Starting with this issue the *G.E.C. Journal* will be published quarterly instead of twice yearly. This reversion to pre-war practice has become necessary in order to provide readers, particularly overseas, with adequate information of the Company's many important technical developments and activities.

G.E.C. Journal

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WOOLWICH GENERATING STATION OF THE B.E.A., LONDON DIVISION

A general view of the turbine house equipped throughout with G.E.C. turbo-alternators of a total capacity of 102,500 kW. A fourth 30,000 kW set is now being built for this station.

Gas Carburising

By D. M. DOVEY, M.A., A.R.I.C., and I. JENKINS, M.Sc., A.I.M.

G.E.C. Research Laboratories.

The reactions occurring within a carburising box are discussed. A comparison is made of various carburising atmospheres tested in the laboratory; therefrom, the effect of differences in the concentration of certain constituents in carburising atmospheres is illustrated. The mechanism of "sooting" and the importance of gas recirculation are discussed. Possible methods of gas generation and the considerations involved in furnace and generator design are listed. The flexibility of control obtainable during carburisation is illustrated by treatment in a commercial plant.

1. INTRODUCTION.

FOR many years the most widely-used method of carburising iron and steel has been that of packing the articles to be treated in a solid carburising mixture in a box and of then heating the box to a temperature near to 900 degs. C. for a time sufficient to produce the required depth of carburised case. The carburising compound is usually a mixture of hard wood charcoal with an oxide or carbonate of the alkalis or alkaline earths. Such a mixture, when heated, will evolve gases capable of reacting on the metal surface and, thereby, of supplying carbon to the steel. This carbon goes into solid solution in the iron and then diffuses inwards away from the surface while, at the same time, more carbon is supplied by fresh gas molecules diffusing to the metal. Thus, when carburising is in progress, there is a continuous cycle going on involving the carburising compound, the gases present in the box and the iron. On the one hand, the gases pick up carbon by reaction with the carburising compound; on the other hand, they are losing carbon to the iron by the reverse reaction. Pack carburising is, then, an example of gas carburising wherein the carburising gases are generated and reactivated in the same container as the work. Obviously many advantages would be gained if the carburising gases could be produced in a separate generator and fed over the work; such processes are now well established and are known in general as "gas carburising."

Pack carburising necessitates the heating of heavy boxes filled with the compound and the work to the carburising temperature. Compared with the gaseous process such an operation has the following disadvantages:

1. It requires a longer overall heat-treatment time.
2. A large proportion of the heat supplied is taken up in heating material other than the work.
3. The temperature uniformity cannot be controlled so accurately.
4. There is no flexibility in control over the carburising strength of the atmosphere in the box once treatment has started.
5. Direct quenching, though possible, requires an intermediate riddling operation.
6. It is dirty.

In two respects, however, pack carburising possesses an advantage:

1. The carburising compound is in contact with the entire surface of the work; there is no screening or starving of any section.

In order to ensure uniformity of gas carburising, the most satisfactory arrangement is to have the atmosphere recirculated within the carburising chamber by means of a fan. Even so, the placing of flat areas in contact must be avoided.

2. The work is bedded in and supported by the mixture.

In the gas carburising process heat-resisting supports have to be provided to carry the work in the most suitable fashion.

In addition to "pack" and "gas" carburising there is a third process wherein the articles to be treated are dipped in a bath of molten salts at the carburising temperature; a mixture of 50/50 sodium cyanide and sodium carbonate is frequently used. This "liquid carburising" has its main application in the treatment of small parts for the production of light cases of the order of 0·010 ins. to 0·025 ins. deep. Both nitriding and carburisation of the steel occur during the heat-treatment.

2. THE MECHANISM OF CARBURISATION BY GASES.

A 3 per cent nickel case-hardening steel was carburised at 900 degs. C. in a carburising compound containing 80 per cent of oakwood charcoal and 20 per cent of barium carbonate for two and a half hours, after which time a sample of the gas from that surrounding the specimen was rapidly extracted and analysed. The analysis indicated that there were the following approximate percentages of gases present :

CO_2 1 per cent ; CO 33 per cent ;
H_2 16 per cent.

These are the gases which serve to carry carbon from the carburising compound to the surface of the steel.

There are several ways in which reaction can occur between these gases (CO, CO_2 and H_2) and carbon, and in order to build up a picture of how carbon is transferred by them from the compound to the work, it is necessary to know how some simpler systems behave.

(a) The reaction of Carbon Monoxide and Carbon Dioxide with Carbon.

If carbon were sealed up in a box in an atmosphere of carbon dioxide and the box then heated to 900 degs. C., it would be found that the reaction

$$CO_2 + C \rightarrow 2CO$$

had proceeded to some extent. Further if an inert gas such as nitrogen were admitted to the box, it would be found that the concentrations of carbon monoxide and dioxide in the box would adjust themselves so that the relationship

$$\frac{p^2CO}{pCO_2} = K_1$$

was always obeyed where :

p = partial pressure of the gas.
K_1 = the equilibrium constant for the reaction; it has a fixed value at a fixed temperature.

In Table 1 are given the values of K_1 for this reaction at various temperatures.

(b) The reaction of Hydrogen with Carbon.

If the same experiment were carried out as in (*a*) but using hydrogen instead of carbon dioxide, the reaction

$$2H_2 + C \rightarrow CH_4$$

would proceed. As previously, there would be a relationship

$$\frac{pCH_4}{p^2H_2} = K_2$$

In Table 1 are given values of K_2 at various temperatures.

In both the reactions given above, the same equilibrium ratios would be achieved if carbon monoxide were used instead of carbon dioxide or methane instead of hydrogen, the only difference being that carbon would be deposited in these mixtures, whereas it was taken up in the former case. Thus, at a given temperature, mixtures of carbon monoxide and dioxide having the value $\frac{p^2CO}{pCO_2}$ greater than K_1 and mixtures of methane and hydrogen having the value $\frac{pCH_4}{p^2H_2}$ greater than K_2 are carbon-forming.

The gas in the carburising box was found to be a mixture of carbon monoxide, carbon dioxide, and hydrogen, and was therefore capable of reacting with carbon by both (*a*) and (*b*) above. In addition, reaction can occur between these gases independently of carbon as follows :

$$CO + H_2O \rightleftharpoons CO_2 + H_2$$

and again, it is found that a relationship holds of the type :

$$\frac{pCO_2 . pH_2}{pCO . pH_2O} = K_3$$

Values of K_3 at various temperatures are given in Table 1.

It is obvious from the nature of this reaction that water vapour is a decarbonising agent, since

TABLE 1

VALUES OF EQUILIBRIUM CONSTANTS FOR THE REACTIONS:

(1) $CO_2 + C \rightleftharpoons 2CO$
(2) $2H_2 + C \rightleftharpoons CH_4$
(3) $CO + H_2O \rightleftharpoons H_2 + CO_2$

Temp. °C.	$K_1 = \frac{P^2CO}{PCO_2}$	$K_2 = \frac{PCH_4}{P^2H_2}$	$K_3 = \frac{PCO_2 . PH_2}{PCO . PH_2O}$
400	$9{\cdot}2 \times 10^{-5}$	14·1	14·1
450	$5{\cdot}6 \times 10^{-4}$	6·02	7·04
500	$3{\cdot}7 \times 10^{-3}$	2·34	4·88
550	0·0186	1·00	3·41
600	0·0794	0·467	2·54
650	0·347	0·251	1·95
700	1·01	0·138	1·54
750	2·98	0·079	1·26
800	10·0	0·050	1·05
850	17·2	0·032	0·892
900	37·6	0·021	0·764
950	74·1	0·014	9·672
1000	143	0·009	0·592
1050	462	0·007	0·527
1100	759	0·005	0·474
1150	822	0·004	0·435

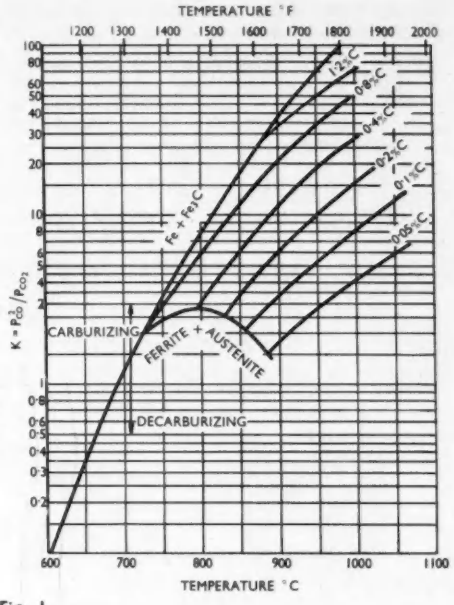
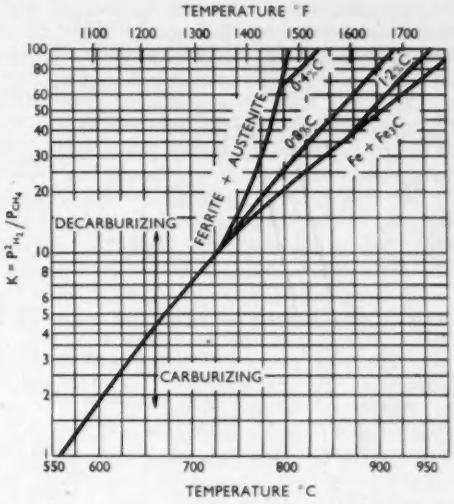
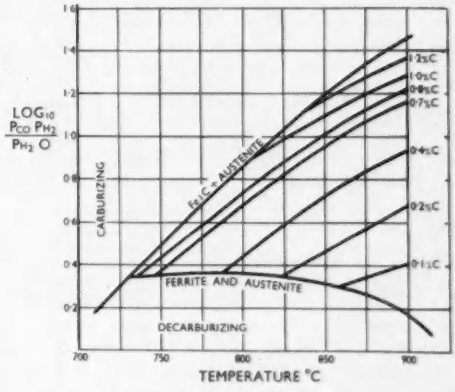


Fig. 1.—
(*a*) Curve of equilibrium values for the reaction $CO_2 + C_{Fe} \rightleftharpoons 2CO$.



(*b*) Curve of equilibrium values for the reaction $2H_2 + C_{Fe} \rightleftharpoons CH_4$.



(*c*) Curve of equilibrium values for the reaction $CO + H_2 \rightleftharpoons C_{Fe} + H_2O$

an addition of water vapour to this system at equilibrium would increase the carbon dioxide at the expense of the monoxide.

These three reactions are sufficient to enable one to state whether a gas mixture containing carbon monoxide, carbon dioxide, hydrogen and methane together with nitrogen, which is inert, will be carbon-forming or carbon-removing at a specific temperature. In general, the higher the methane and carbon monoxide content and the lower the carbon dioxide and water vapour content, the greater is the " carbon potential " of the mixture.

The important fact is not whether a given mixture of gases will produce carbon in the form of soot, but whether the mixture will give up carbon to steel and, further, to what concentration this carbon will attain. Reaction occurs on the surface of steel in these gas mixtures and these reactions are governed by similar laws as exist in the case of reaction with free carbon. Another factor, however, must be introduced which is the concentration of carbon in the steel ; thus equation (1) becomes

$$CO_2 + C_{Fe} \rightleftharpoons 2CO$$

when C_{Fe} is the concentration of carbon in solution in the steel for which the equilibrium constant K'_1 is given by

$$\frac{p^2CO}{pCO_2 . (C_{Fe})} = K'_1$$

At a fixed temperature, then, there are fixed values of $\frac{p^2CO}{pCO_2}$ which correspond to fixed values of (C_{Fe}). A corresponding equation holds for the system $2H_2 + C_{Fe} \rightleftharpoons CH_4$

$$\frac{pCH_4}{p^2H_2 (C_{Fe})} = K'_2$$

In fig. 1 are indicated the values of the carbon

concentration which are in equilibrium with mixtures of (*a*) CO/CO_2 and (*b*) H_2/CH_4 at various temperatures. It may be seen that the curve for solid carbon is close to that for saturated austenite and, broadly speaking, it is this fact together with the knowledge of the fundamental gas reactions which form the picture of the carbon transfer in a pack-carburising box where the atmosphere is picking up carbon continuously from the charcoal on the one hand and losing carbon to the steel on the other.

3. FACTORS GOVERNING SELECTION OF ATMOSPHERE.

Data given above are sufficient to indicate what are some of the desirable and undesirable constituents of atmospheres intended for gas carburising. Still to be considered is the effect of gas composition on the speed with which carbon is taken up by the steel. The data already obtained indicate whether and to what extent an atmosphere will carburise, but give no indication of the speed with which carburising will occur.

Factors other than gas composition influence this speed; for example, the condition of the steel surface and the rate of carbon diffusion. Thus, if steel is treated in a gas mixture which will etch the surface of the steel prior to carburisation, more rapid carburisation is obtained than is the case when no prior etching is carried out. In fig. 2 are given photomicrographs of similar steels after being carburised for similar times in the etched and unetched condition respectively. It is important to note, however, that after some time at maximum temperature a point will be reached when the absorption of carbon will be governed by the rate of diffusion of carbon from the surface to the centre of the steel, this rate being slower than that which the original carburising gas mixture is capable of maintaining. Therefore, the surface condition of the steel is of less importance when deep cases, involving long treatment times, are required.

With respect to the carburising speed of an atmosphere, an indication is needed as to whether there is a wide difference between the following three general types:

(*a*) An atmosphere consisting mainly of carbon monoxide.

(*b*) An atmosphere consisting mainly of methane and hydrogen.

(*c*) An atmosphere consisting mainly of carbon monoxide and hydrogen.

It was shown by Bramley[1] that (*c*) was superior to (*a*). It is known that the rate of methane breakdown is comparatively slow and that the gases present in pack-carburising boxes, where there is a high-carburising rate, are mainly carbon monoxide and hydrogen. In general, the

[1] A. Bramley and G. Turner: *Iron and Steel Institute*, 1928, *Carnegie Scholarship Memoirs*, vol. 17, p. 48.

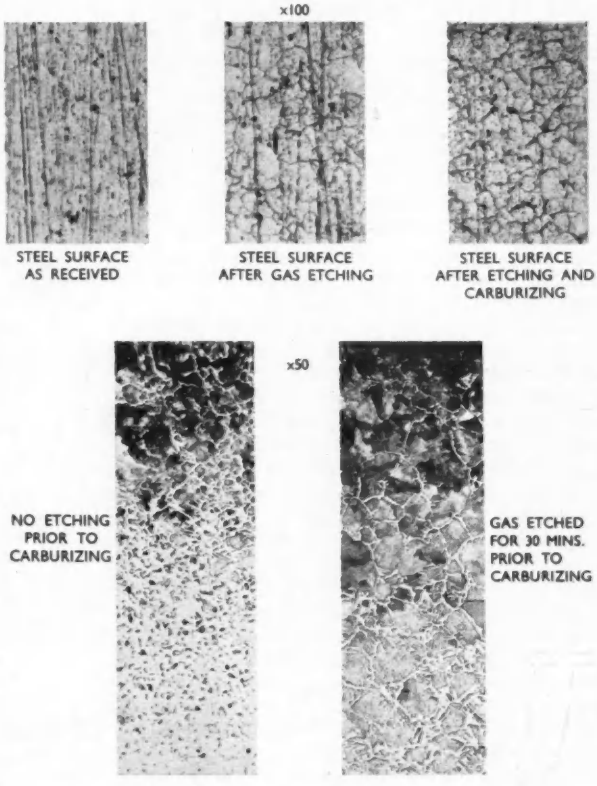

×100
STEEL SURFACE AS RECEIVED
STEEL SURFACE AFTER GAS ETCHING
STEEL SURFACE AFTER ETCHING AND CARBURIZING
×50
NO ETCHING PRIOR TO CARBURIZING
GAS ETCHED FOR 30 MINS. PRIOR TO CARBURIZING

Fig. 2.—Effect of gas etching on the degree of carburisation. Etching gas: 4·8% CO_2; 10·8% CO; 15·6 % H_2; 2·3% H_2O; 66·5% N_2.
Carburising gas: 10·7% CO; 15·0 % H_2; 74·3% N_2.
Etching treatment: 30 minutes at 950 degs. C.
Carburising treatment: 5 hours at 950 degs. C.

velocity of carbon supply from a set of specified constituents in the atmosphere will be proportional to the extent that the constituents are " out of balance " on the carburising side of the equilibrium value. For example, in methane-hydrogen mixtures, an increase in the methane concentration will result in an increase in both the carburising potential and the carburising speed of the reaction. Referring again to the curves and data in Table 1 and fig. 1 it may be seen that the values of $\frac{pCH_4}{p^2H_2}$ and $\frac{p^2CO}{pCO_2}$ for saturated austenite lie close to those for free carbon, hence if the carburising potential is increased greatly, an undesirable deposition of free carbon would be expected. This is not a real danger in the case of simple atmospheres containing carbon monoxide, carbon dioxide, hydrogen and water vapour since the actual weight of carbon available per cu. ft. at the temperature of carburising is not excessive even when the atmosphere is 100 per cent carbon monoxide. An atmosphere consisting of 100 per cent methane, however, has a much greater weight of carbon available per cu. ft. The calculated values are :

Carbon deposited from 1 cu. ft. (measured at N.T.P.) of gas at 900 degs. C. before reaching equilibrium :

100 per cent CO	100 per cent CH_4
Reaction :	Reaction :
$2CO \rightarrow CO_2 + C$	$CH_4 \rightarrow C + 2H_2$
1 cu. ft. $\rightarrow$ 0·36 gms. carbon.	1 cu. ft. $\rightarrow$ 14 gms. carbon.

Thus whereas high concentrations of carbon monoxide are desirable, together with low concentrations of carbon dioxide and water vapour, nevertheless, on this evidence, the concentration of methane over the work cannot be increased indefinitely without due consideration being paid to the possibility of sooting. In practice quite large concentrations of methane may be tolerated above the equilibrium value and, in fact, serve a useful purpose in that a balance is struck whereby the atmosphere is kept powerful enough to supply as much carbon to the steel as the steel can accept and yet the free carbon deposition is only slight, being a light fluffy deposit on the surface of the work ; this condition is dependent not only on the composition of the atmosphere but on how the atmosphere is brought into contact with the work. These various factors will be discussed later.

The above knowledge enables us to describe those factors which determine the quality of gas carburising atmospheres :

1. The atmosphere must be such that either any or all of the following reactions proceed continuously from left to right :

(*a*) $2CO \rightleftharpoons CO_2 + C_{Fe}$
(*b*) $CH_4 \rightleftharpoons 2H_2 + C_{Fe}$
(*c*) $CO + H_2 \rightleftharpoons C_{Fe} + H_2O$

Examination of the equilibrium diagram for reaction (*a*) shows that only a low percentage of carbon dioxide (or water vapour) can be tolerated in carbon monoxide. On the other hand, in reaction (*b*) a low percentage of methane is sufficient to afford a carburising atmosphere.

2. Dilution with nitrogen is undesirable. If carbon monoxide, containing a little carbon dioxide, is diluted with nitrogen the amount of carbon dioxide in the diluted atmosphere must be reduced if carburising potential is to be maintained, since the carbon dioxide concentration must remain inversely proportional to the square of the carbon monoxide concentration. The dilution of carbon monoxide with nitrogen, therefore, results in an atmosphere very susceptible to additions of decarburants.

3. The atmosphere must be such as not only to carburise rapidly when it first comes into contact with the work, but also to maintain this power throughout the heat-treatment.

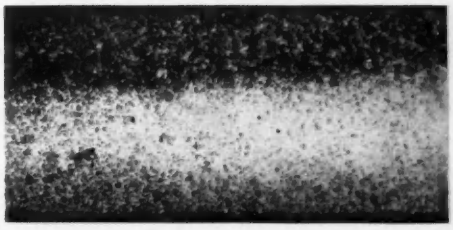


Fig. 3.—Carburisation of mild steel in town gas showing uneven surface.

Known data suggest that the most rapid speed of carburising is attained by the reaction (*c*)

$$CO + H_2 \rightleftharpoons C_{Fe} + H_2O$$

$$K_c = \frac{(CO)\ (H_2)}{(C_{Fe})\ (H_2O)} = \frac{K_a}{K_d}$$

Where $K_d = \frac{(H_2)\ (CO_2)}{(CO)\ (H_2O)}$

It would appear that an atmosphere consisting of comparable quantities of hydrogen and carbon monoxide together with a little methane would carburise rapidly. The amount of water vapour (or CO_2) which may be tolerated by a mixture of carbon monoxide and hydrogen is low e.g. at 900 degs. C. a mixture of 50 per cent CO, 50 per cent H_2, could tolerate only 1·7 per

cent H_2O + 1·3 per cent CO_2 before decarburising 0·7 per cent C-steel (fig. 1 (*c*)). It is obvious that a means must be found of ensuring that such an atmosphere is not quickly "spent," i.e. either sufficient reactive hydrocarbons must be present to offset the water vapour and carbon dioxide formed during carburisation, or the rate of throughput of atmosphere must be high.

4. Sooting must be avoided.

Some hydrocarbons will deposit soot very rapidly, and if present their concentration must be carefully controlled. The least reactive hydrocarbon is methane.

4. LABORATORY EXPERIMENTS.

The sources of carbon from which carburising gases may be prepared economically on a commercial scale are three :

1. Town gas.
2. "Bottled" liquids or gases.
3. Charcoal.

A series of experiments was carried out involving many different methods of production of carburising atmospheres. The atmospheres produced were then compared by passing them, for various lengths of time, over steel specimens maintained at carburising temperatures. It must be stressed that no attempt was made to recirculate the gases over the work during treatment.

(a) Town Gas, as supplied.

(Analysis : 2·6 per cent CO_2 ; 2·4 per cent C_nH_m ; 11·0 per cent CO ; 21·5 per cent CH_4 ; 56.0 per cent H_2 ; 2·0 per cent H_2O ; 4·5 per cent N_2.

Carburisation of mild steel in town gas was carried out at 950 degs. C. The results were inconsistent. Carburisation was always accompanied by fairly heavy sooting of the steel, resulting in non-uniformity of the depth and carbon content of the case. This is illustrated in fig. 3, which shows the differences between the cases on opposite sides of the specimen.

(b) Town Gas + Burnt Town Gas.

(Composition of burnt town gas : 4·8 per cent CO_2 ; 10·8 per cent CO ; 15·5 per cent H_2 ; 2·3 per cent H_2O ; 66·6 per cent N_2).

Dilution of town gas with burnt town gas from a standard G.E.C. burner decreased the amount of sooting, but only at the expense of a serious reduction in the rate of carburisation (Table 2).

(c) Town Gas after scrubbing.

(Analysis : 9·0 per cent CO ; 52·5 per cent H_2 ; 20·1 per cent CH_4 ; 18·5 per cent N_2 ; 0·0 per cent CO_2, O_2, H_2O and C_nH_m).

The carbon dioxide, free-oxygen, water vapour and unsaturated hydrocarbons were reduced in two ways, i.e. (1) by scrubbing with suitable reagents and (2) by treating the gas over charcoal at 750 degs. C. The atmosphere produced by both processes was strongly carburising (Table 3). After treatment, the specimens were covered with a light film of soot.

(d) Burnt Town Gas and Propane.

A series of mixtures of burnt town gas and propane were prepared and tested. The results are summarised in Table 4, whilst the structure and case depth obtained are illustrated in fig. 4 (*b*). Fig. 5 shows the effect of time on the

TABLE 2

Carburisation of 0·15 per cent Carbon Steel at 925 degs. C. for 5 hours in Town Gas — Burnt Town Gas Atmosphere

Carburising Atmosphere		Weight Increase Mgms/mm² ×10³	Case Depth ins.	Comments
Town Gas	Burnt Town Gas			
100	0	37·5	0·037	Heavy soot. Adherent surface deposit. Non-uniform case.
75	25	31·3	0·032	Heavy soot. Adherent surface deposit. Non-uniform case.
50	50	27·2	0·030	Light soot. Readily brushed off. Uniform case.
25	75	19·2	0·017	Very light soot. Readily brushed off. Uniform case.
10	90	2·1	Trace	No soot.

case-depth obtained with a nickel-chrome steel carburised in 28 per cent propane —72 per cent B.T.G. Above 24 per cent propane, sooting was excessive but on the whole was less than that occurring with air - propane mixtures.

TABLE 3

Carburisation in purified Town Gas.
Analysis: 9·0 per cent CO; 52·5 per cent H_2; 20·1 per cent CH_4; 18·5 per cent N_2.

Steel	5 Hours at 900° C.		5 Hours at 1,000° C.	
	Weight Increase Mgms/mm² ×10³	Case Depth ins.	Weight Increase Mgms/mm² ×10³	Case Depth ins.
Mild Steel	56·0	0·060	86·0	0·080
Nickel Steel	43·0	0·040	77·0	0·060
Nickel-Chromium Steel			80·1	0·076

(e) Burnt Town Gas treated over Charcoal at 1,000 degs. C. + Propane.

Approximate composition for 2½/1 air : gas ratio in gas burner : 20 per cent *CO* ; 15 per cent H_2 ; 64 per cent N_2 ; 1 per cent CH_4.

The atmosphere as generated had fairly strong carburising properties giving good case depth with a surface carbon content corresponding to about eutectoid composition. Additions of propane up to 4 per cent increased the carburising power markedly and only very light sooting occurred. Table 5 gives the results obtained and a microphotograph of the type of case obtained is given in fig 4 (*c*).

(f) Town Gas mixed with Air and treated over Charcoal.

By passing air and town gas mixed in approximately equal proportions over charcoal heated to 1,000 degs. C. a gas of the following composition was obtained :

24 per cent *CO* ; 1 per cent CH_4 ; 36 per cent H_2 ; 39 per cent N_2 ; $< 0{\cdot}1$ per cent H_2O.

The results obtained on mild steel with the gas as generated and after the addition of 2 per cent of propane are shown in fig. 6 (*a*) and (*b*).

(g) Butane.

Experiments with pure butane resulted in the rapid sooting-up of the reaction tube so that even at very low gas velocities the passage of the hydrocarbon gas through the tube was stopped completely after half an hour.

Mixtures of air with butane or burnt town gas with butane reduced the sooting to some extent. However, it was not possible to reduce the con-

TABLE 4

CARBURISATION OF STEELS IN BURNT FUEL GAS — PROPANE ATMOSPHERES

Burnt Fuel Gas: 4·8 per cent CO_2; 10·8 per cent CO; 15·6 per cent H_2; 2·3 per cent H_2O; 66·6 per cent N_2

Rate of Gas Flow: 5ft./min.

		0·15% C Steel at 925° C.			3·17% Ni ; 0·16% C Steel at 900° C.			3·18% Ni ; 1·1% Cr ; 0·13% C Steel at 900° C.		
Propane per cent	Time hrs.	Weight Increase Mgms/mm² ×10³	Surface Carbon Analysis per cent	Case Depth ins.	Weight Increase Mgms/mm² ×10³	Surface Carbon Analysis per cent	Case Depth ins.	Weight Increase Mgms/mm² ×10³	Surface Carbon Analysis per cent	Case Depth ins.
20	2½	29·5	0·92	0·027	13·2	0·37	0·010	10·0	0·52	0·027
20	5	40·7	1·11	0·037	16·5	0·47	0·017	13·5	0·54	0·037
20	10	64·5	1·22	0·055	23·0	0·59	0·027	17·5	0·59	0·050
24	2½	30·2	1·08	0·035	16·2	0·58	0·017	11·4	0·52	0·033
24	5	43·7	1·09	0·050	23·1	0·68	0·028	15·1	0·59	0·045
24	10	72·0	1·19	0·068	31·7	0·77	0·034	21·3	0·66	0·055
28	2½	31·5	0·98	0·038	18·6	0·64	0·023	12·5	0·56	0·036
28	5	46·6	1·17	0·057	26·9	0·78	0·032	16·5	0·63	0·048
28	10	73·3	1·22	0·078	32·0	0·83	0·040	22·4	0·71	0·058
32	2½	31·9	1·10	0·040	19·2	0·66	0·026	—	—	—
32	5	50·5	1·20	0·062	27·3	0·79	0·035	—	—	—
32	10	74·7	1·23	0·083	32·5	0·85	0·046	—	—	—

centration of butane sufficiently to eliminate sooting without also suppressing completely the carburising reaction.

(h) Air-Propane Mixtures.

Controlled volumes of propane and of air were led to a small mixing vessel and thence to the furnace tube containing the specimen. As in the case of experiments with diluted butane mixtures carburisation was accompanied by sooting which increased with the concentration of propane and was excessive above approximately 25 per cent of the hydrocarbon. A photomicrograph of the case depth obtained at the optimum conditions of treatment is given in fig. 4 (*a*).

(i) Steam-Charcoal Gas.

A dry atmosphere was produced by passing steam over charcoal heated to approximately 1,000 degs. C. The atmosphere contained 49 per cent CO ; 48·5 per cent H_2 ; and 2·5 per cent CH_4 and, after complete drying, gave a rate of carburisation which was at least equal to that obtained with any other of the atmospheres tested. The work was completely free from soot. Fig. 7 indicates the hardness of the case of specimens treated in this atmosphere (oil-quenched from 775 degs. C.) compared with two other carburising treatments.

Judging the results achieved on the depth and uniformity of the case together with the cleanliness of the work, the atmospheres which were generated over charcoal at approximately 1,000 degs. C. were superior. The experimental atmospheres may be listed as follows in order of merit:

1. Steam-charcoal gas :
   Approximate analysis 49 per cent CO ; 49 per cent H_2 ; 2 per cent CH_4.

2. Town Gas + air, heated over charcoal, + 2 per cent propane :
   Approximate analysis 24 per cent CO ; 36 per cent H_2 ; 1 per cent CH_4 ; 39 per cent N_2.

3. Burnt town gas, heated over charcoal, + 4 per cent propane :
   Approximate analysis 20 per cent CO ; 15 per cent H_2 ; 1 per cent CH_4 ; 64 per cent N_2.

4. Scrubbed town gas :
   Approximate analysis 9 per cent CO ; 53 per cent H_2 ; 21 per cent CH_4 ; 17 per cent N_2.

5. (*a*) Burnt town gas + propane :
   Approximate analysis 28 per cent C_3H_8 ; 3 per cent CO_2 ; 8 per cent CO ; 12 per cent H_2 ; 2 per cent H_2O ; 47 per cent N_2
   (*b*) Town gas + burnt town gas :
   Approximate analysis of 50/50 mixture 5 per cent CO_2 ; 11 per cent CO ; 35 per cent H_2 ; 2 per cent H_2O ; 11 per cent CH_4 ; 1 per cent C_nH_m; 35 per cent N_2.

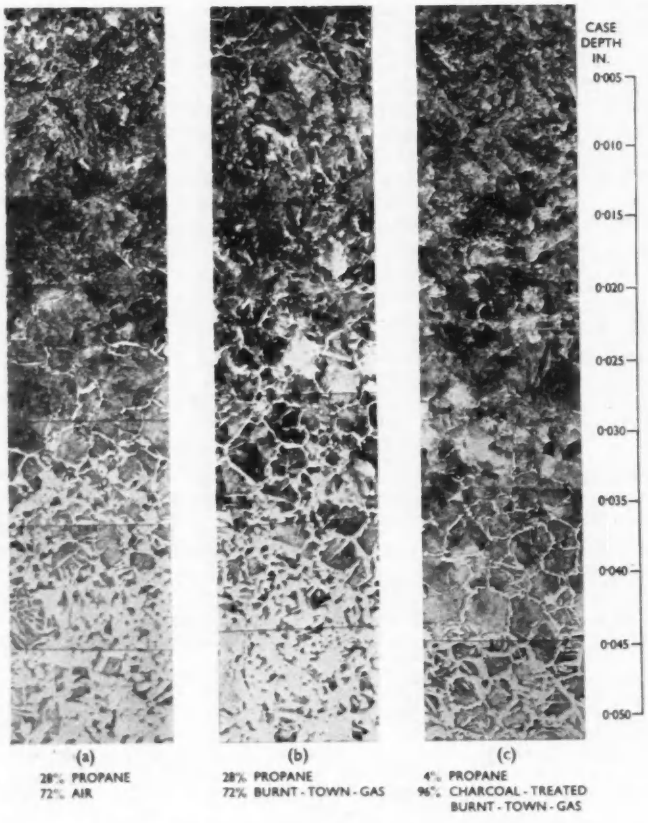


Fig. 4.—0.15 per cent carbon steel carburised at 925 degs. C. for 5 hours in various diluted propane atmospheres.

(*c*) Town gas :
Analysis 2·6 per cent CO_2 ; 2·4 per cent C_nH_m ; 11·0 per cent CO ; 21·5 per cent CH_4 ; 56·0 per cent H_2.

6. Butane C_4H_{10}.

It is obvious from the above that :

1. The most desirable atmosphere is one consisting of 49 per cent CO ; 49 per cent H_2 ; 2 per cent CH_4.
2. Dilution of this mixture with nitrogen does not change its characteristic behaviour but reduces its power.
3. Concentrations of methane in excess of the equilibrium value may be tolerated in such a mixture without excessive sooting.
4. The presence of small quantities of carbon dioxide and water vapour markedly reduce the carburising power of the mixture.
5. The presence of hydrocarbons, sufficient to offset the presence of a few per cent of carbon dioxide and water vapour leads to excessive sooting and hence to unsatisfactory carburisation.
6. Neat hydrocarbons cannot be passed directly over steel without rapid sooting-up occurring.

5. THE CAUSE OF "SOOTING".

The inferences nos. 1 to 4 and no. 6 are not unexpected in view of the conclusions reached on more fundamental data regarding the desirable compositions of a carburising atmosphere. Statement no. 5 needs some further explanation in order to clarify the reasons for this inability to reduce the percentage of carbon dioxide and water vapour, by addition of reactive hydrocarbons without forming soot. It was noted that, for instance, mixtures of burnt town gas and propane required a concentration of 28 per cent of propane before high carburising rates were achieved ; at the same time sooting occurred. The combined percentage of carbon dioxide and water vapour in the mixture was approximately 5 per cent and if it is assumed that reactions such as

$$C_3H_8 \rightarrow 2CH_4 + C \qquad \text{(available)}$$

and

$$C + CO_2 \rightarrow 2CO \qquad \text{(available)}$$

occur at carburising temperatures, it is obvious immediately that quantities of propane appar-

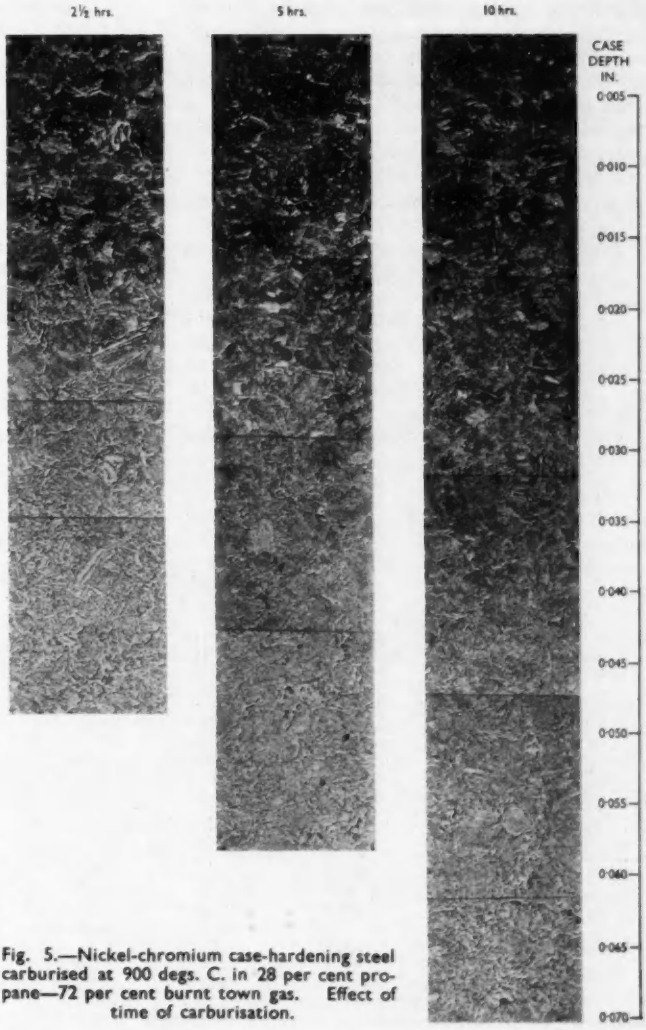


Fig. 5.—Nickel-chromium case-hardening steel carburised at 900 degs. C. in 28 per cent propane—72 per cent burnt town gas. Effect of time of carburisation.

ently far in excess of those required to convert the carbon dioxide and water vapour to carbon monoxide and hydrogen are, in fact, required to produce a strongly carburising atmosphere. This may be explained as follows : As the equilibrium curves for carbon and saturated austenite indicate, all strongly carburising atmospheres are capable of producing free carbon, i.e. of sooting. If there is more than one process by which breakdown of gas constituents to carbon may occur, the equilibrium curves indicate only the direction in which the reactions will tend to go, but they cannot indicate which will be the preferred mechanism. Obviously, in a rapidly carburising atmosphere carbon must be set free on the steel surface, from the gases present, sufficiently rapidly to diffuse into the surface, against a high concentration of carbon already produced in solid solution, at a speed at least equal to the amount of carbon diffusing into the core from the case. An ideal gas mixture would be therefore, one in which :

(*a*) No reaction occurs in the gas phase alone to produce free carbon.

(*b*) Rapid reaction occurs on the surface of steel to produce carbon.

(*c*) The carbon produced on the steel should be preferentially of carbon atoms linked to the iron but not to each other. In this case solution of carbon in the iron is favoured rather than the production of carbon in the form of soot nuclei.

Considering the extreme examples of atmospheres used in the experiments it may be seen that, first, steam-charcoal gas is not excluded from conditions (*a*), (*b*) and (*c*) and that, second, butane is known to depart from condition (*a*) and (*c*). It has been shown that for methane and its homologues thermal cracking can occur not only over a catalyst, but also in the gas phase. The first result of this cracking is the production of an unsaturated hydrocarbon, e.g. :

$$\underset{\text{methane}}{2CH_4} \rightarrow \underset{\text{ethylene}}{C_2H_4} + 2H_2$$

$$\underset{\text{butane}}{\begin{array}{c}CH_3\\|\\CH_2\\|\\CH_2\\|\\CH_3\end{array}} \rightarrow \underset{\text{butene}}{\begin{array}{c}CH_2\\|\\CH\\|\\CH_2\\|\\CH_3\end{array}} + H_2$$

This pyrolysis begins, in the case of methane, at approximately 680 degs. C. in the absence of a catalyst. The homologues of methane began to break down at progressively decreasing temperatures according to the number of carbon atoms present in the molecule, e.g. butane begins at approximately 450 degs. C. The unsaturated hydrocarbons thus formed can polymerise at even lower temperatures, e.g. ethylene will polymerise at 400 degs. C. and butene at 350 degs. C. At any given temperature a range of polymers differing in their degree of polymerisation are formed from a given hydrocarbon. These

TABLE 5

CARBURISATION OF STEELS IN CHARCOAL — TREATED BURNT TOWN GAS AND PROPANE

Analysis of Diluting Gas : 20·8 per cent CO; 1·2 per cent H_2; 78 per cent N_2. Rate of Flow : 5ft./min.

		0·15 per cent C Steel at 925° C.			3·17 per cent Ni; 0·16 per cent C Steel at 900° C.		
Propane per cent	**Time** hrs.	**Weight Increase** Mgms/mm² ×10³	**Surface Carbon** Analysis per cent	**Case Depth** ins.	**Weight Increase** Mgms/mm² ×10³	**Surface Carbon** Analysis per cent	**Case Depth** ins.
2	2½	33·8	1·09	0·029	28·9	0·82	0·027
2	5	42·8	1·20	0·044	40·2	1·00	0·038
2	10	51·2	1·28	0·068	48·0	1·11	0·047
3	2½	—	—	—	30·6	0·95	0·030
3	5	—	—	—	43·7	1·08	0·042
3	10	—	—	—	50·1	1·16	0·051
4	2½	44·4	1·19	0·034	33·2	1·04	0·032
4	5	54·2	1·25	0·054	44·1	1·13	0·042
4	10	66·4	1·34	0·076	51·0	1·16	0·054
6	2½	46·3	1·19	0·037	—	—	—
6	5	58·1	1·24	0·056	—	—	—
6	10	74·0	1·30	0·083	—	—	—

polymers in turn may produce soot by further pyrolysis. Such breakdown reactions are catalysed by iron or nickel.

This behaviour of hydrocarbons on heating indicates why such hydrocarbons are unsatisfactory for addition in large concentrations to decarburising atmospheres with the purpose of rendering the atmospheres capable of carburising. In the first place soot formation can occur independently of the steel surface, thus weakening the atmosphere, and, secondly, polymerisation can occur actually on the surface of the steel which results in soot formation and thereby inhibits rapid carburisation.

It should be noted that town gas, as received, is much less suitable for carburising than it is after being scrubbed. The scrubbing, whether by hot charcoal or by other means, removes unsaturated hydrocarbons, carbon dioxide, and water vapour. It is to be expected that the unsaturated hydrocarbons would cause rapid sooting, but it is also possible that the decarburants present catalyse the formation of soot. The methane concentration in town gas is high and the carbon reserve of the atmosphere is high. It would be useful to know how changes in the methane concentration to values below 20 per cent would affect the relative sooting and carburising capabilities of the gas when decarburants are present. In this respect, it should be pointed out that a gas mixture of the "unbalanced" type (e.g. $CH_4 + H_2 + CO + CO_2 + H_2O$ having a CH_4/H_2^2 ratio sufficient to cause carburisation but having a CO_2/CO^2 ratio sufficient to cause decarburisation) will not necessarily carburise when passed over steel, although the gas may contain sufficient methane,on balance, to form soot at 900 degs. C. if the reactions were allowed to come to equilibrium at that temperature: If optimum conditions obtain for carburisation by the methane, i.e. no carbon is released by side-reactions from the methane and all the carbon is available for carburisation on the surface of the steel, the instantaneous rate of production of carbon atoms on the steel surface will be governed by the concentrations of the various gases in the atmosphere. The velocity of carbon atom formation would be, then:

$$V=\frac{dn_c}{dt}= a_1CH_4-a'_1(H_2)^2\times C_{Fe} + a_2(CO)^2-a'_2CO_2\times C_{Fe} + a_3(CO)\,(H_2)-a'_3H_2O\times C_{Fe}$$

(Where "a" etc., are the apparent velocity constants.)

If V is positive, carburisation occurs; if negative, decarburisation occurs; if zero, equilibrium is reached.

The relation between a_1, a_2 and a_3 is not known. Hence the initial direction of movement

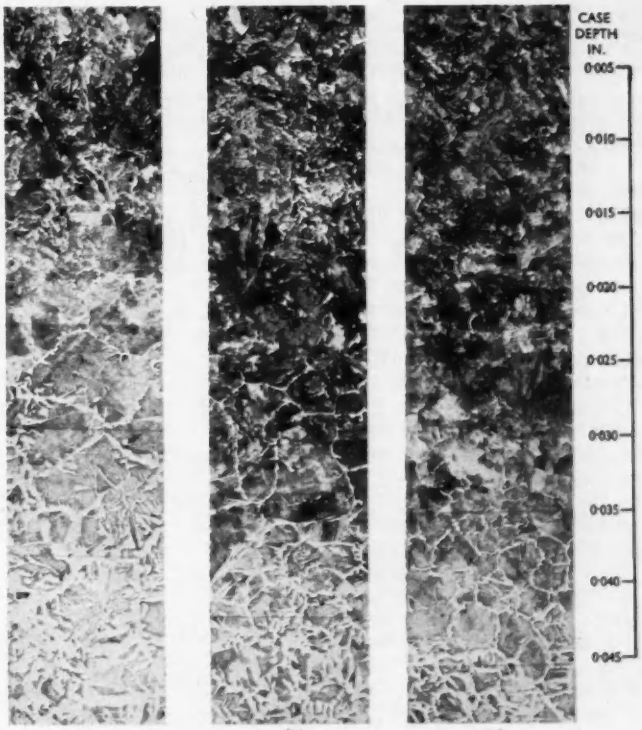


Fig. 6.—0·15 per cent carbon steel carburised at 925 degs. C. for 5 hours in various atmospheres.

of carbon cannot be forecast. In fact, there is some evidence that methane breakdown on steel is slow compared with the other reactions, in which case if the speed of passage of a mixture of gases, such as that described, over the steel were sufficiently rapid, then the steel might be decarburised.

6. RELATION BETWEEN FURNACE DESIGN AND CARBURISING ATMOSPHERE

The small-scale experiments indicated that stabilisation of suitable gases over heated charcoal gave rise to the most suitable carrier atmospheres for gas carburising. There is no doubt that such atmospheres are preferable in all treatments in which, within the heat-treatment chamber, neither mixing of the gas occurs nor the work is moved. In commercial treatments, however, there are two important factors which decide, to some extent, the design of furnace. First, the carburising gas must be uniformly distributed over all the surfaces needing carburising, and, second, the charge must be brought rapidly to temperature and then maintained at a temperature which does not differ from point to point with the charge. Only in such a way may uniformity of treatment be obtained.

The two methods of achieving this result are either by inducing forced circulation over the charge by means of a fan or moving the work in, say, a rotating retort during the treatment; the first method is the more suitable in most cases. The effect on the gas reactions within the carburising chamber resulting from the use of a fan is an important one and is present to some extent in all cases where there is turbulence of gases over the work. If the recirculation velocity of the gas within the carburising chamber is sufficiently high, then complete mixing of the gases in the furnace with fresh gas occurs immediately on admission of the latter.

If the furnace is originally filled with gas A and gas B admitted at a fixed rate, then

$$\log_e \frac{1}{f} = kt$$

where $f = \frac{a}{a+b}$ = fraction of gas A present after time t

$$k = \frac{R}{V} = \frac{\text{Rate of gas supply}}{\text{Gas space in furnace}}$$

t = time from start

e.g. when $t = 0$ $a = 1$, $b = 0$, $f = 1$

When carburisation is in progress reactions will proceed which result in production of decarburants at the expense of carburants, e.g. $CO \rightarrow CO_2$ or $CH_4 \rightarrow 2H_2$. As the amount of oxygen-containing decarburant which may be tolerated is small compared with the quantities of carburants already present, then the rate of production of decarburants, in an atmosphere to which no addition is made, may be regarded as being equal to R in the above equation.

If it is intended to keep a carburising atmosphere of consistent strength in the furnace chamber by the addition of, say, neat hydrocarbon, then the rate of addition of this hydrocarbon will be directly proportional to the rate of production of decarburants (R) and hence to the rate of carbon uptake. If the furnace carries a charge of 5 cwt. of ½-in. diameter bar, the rate of carbon taken up by the steel for the production of a 0·90 per cent carbon case at the rate of 0·010 in. per hour will be of the order of 0·40 lbs./hr. If the furnace atmosphere is

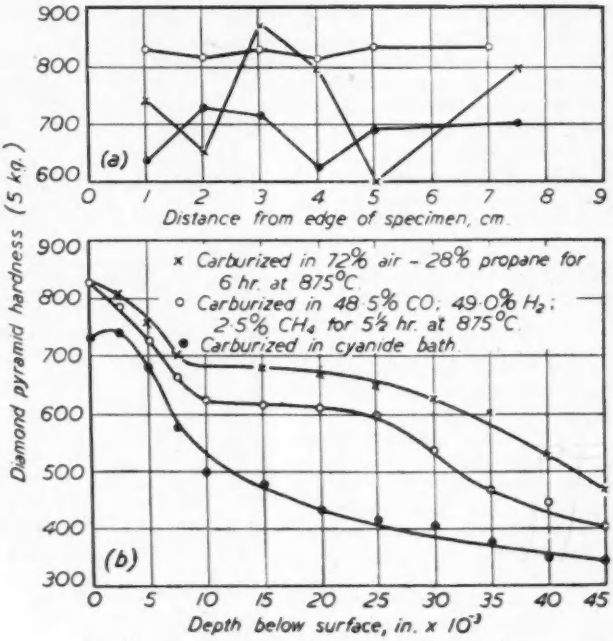


Fig. 7.—Hardness of carburised nickel-chromium-molybdenum steel. All samples O.H. from 775 degs. C.
(*a*) Hardness along surface.
(*b*) Hardness below surface.

maintained at 75 per cent H_2 and 25 per cent CH_4 by the addition of neat butane, then

$$C_4H_{10} \rightarrow 3C_{Fe} + 3H_2 + CH_4$$
$$0{\cdot}64 \text{ lbs.} \rightarrow 0{\cdot}40 \text{ lbs.}$$

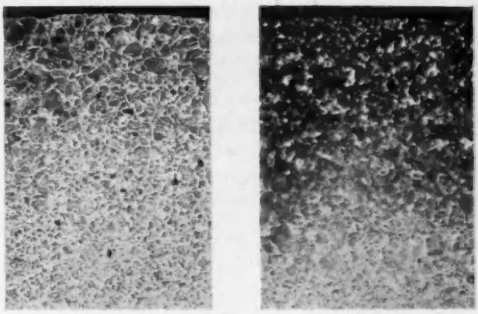
(assuming that no soot is formed). Therefore, approximate rate of addition of butane = 0·64 lbs./hr.= 3·0 cu. ft./hr.

It is apparent that it would not be easy to balance exactly the carbon uptake by a controlled rate of neat hydrocarbon addition. First, the furnace volume will be of the order of 10 cu. ft., and there will be some air-leakage into the furnace, as no furnace is completely gas-tight; this leakage may rob the atmosphere of carbon at a much greater rate than that at which the steel does during the later stages of carburisation. Second, the rate of carbon uptake will vary from charge to charge. Third, no treatment will be absolutely free from soot and the effect of this on the rate of hydrocarbon addition required cannot be estimated. The result is that carburising in rich hydrocarbons can only be successful by establishing arbitrary rates of addition depending upon the type of charge treated, the case required and the leakage factor of the furnace.

The alternative to the use of neat rich hydrocarbons is the use of a " carrier " gas of controlled carburising potential. In the latter case an atmosphere is fed into the furnace at sufficient speed to prevent any appreciable dilution of the furnace gases, due either to air-leakage or to carbon uptake by the steel during the later stages of treatment. For a given mixture of, say, CO, H_2, CO_2, H_2O and N_2 the amount of dilution that may be tolerated to lower the carburising potential from, say, 0·8 per cent C to 0·6 per cent C may be calculated and thus a minimum figure obtained for the rate of gas addition to a particular furnace when carburising is in progress.

7. ATMOSPHERE GENERATORS.

The simplest class of atmosphere generator is that wherein raw gas or liquid is fed from a container into the carburising chamber. Again, there is the choice either of using rich " sooty " hydrocarbons or of using a type of fluid such that there is little or no soot formed by polymerisation reactions and in which the availability of the carbon is controlled. Of the first type are such materials as propane, butane, benzene, petrol fractions and natural oils. Materials of the second type may be compared by testing in furnaces without a fan, since they are comparable with gas atmospheres (1) to (4) previously described. For example, a liquid of controllable carbon potential was fed into a silica tube of the type used in previous experiments containing a mild-steel test-piece at 925 degs. C. The treatment was continued for five hours. In fig. 8 are given photomicrographs of the cases obtained using this liquid at two different values of carburising potential. The surface of the work after treatment presented a clean etched appearance completely free from soot and carburising had occurred uniformly.



LIQUID A x35 LIQUID B x75

Fig. 8.—Mild-steel specimens carburised for 5 hours at 925 degs. C. by " drip-feed " process. Liquids selected from a range of increasing carburising potential.

The second class of atmosphere plant is that in which a suitable mixture of gases is generated external to the furnace. In this second class there are, broadly speaking, two types of equipment.

(A) Atmospheres " stabilised " over carbon at approximately 1,000 degs. C.

(B) Other atmospheres.

Type (A).

These atmospheres are produced free from carbon dioxide, water vapour, and hydrocarbons other than methane, by passing suitable gases over carbon at approximately 1,000 degs. C. A cheap and reactive form of carbon is wood charcoal. The success of this method of production depends upon the nearness of the equilibrium values for carbon and for saturated austenite, respectively, in the systems given in Table 1 and fig. 1. The most reactive atmosphere, as indicated previously, is that derived from the reaction of steam with charcoal resulting in a mixture of carbon monoxide and hydrogen in the ratio of 1 : 1. This is a comparatively expensive process, due to the heat requirement in raising steam, bringing it up to the necessary temperature, and then allowing it to react with charcoal. The consumption of charcoal is high. A second possible atmosphere is that resulting from the passage of air over charcoal at 1,000 degs. C.;

this is approximately 65 per cent N_2, 33 per cent CO, and 2 per cent H_2. It is inferior in quality to steam-charcoal gas in that the high nitrogen and low hydrogen contents are detrimental for reasons previously stated. Although cheaper to produce—since the reaction is exothermic—the consumption of charcoal is high, and precautions have to be taken to prevent excessive temperatures in the combustion zone of the charcoal column.

The other atmospheres of this type are nos. 2 to 4, page 70, and their commercial possibilities are as follows :

No. 2. Town Gas + air over Charcoal at 1,000 degs. C.

This atmosphere, with the addition of a few per cent of propane, was second only to steam-charcoal gas in quality. The difference lies in its nitrogen content (39 per cent). Its production on the commercial scale has attractive features in that, if the ratio of air to gas is suitably chosen (approximately 1 : 1), the charcoal consumption is very low. Furthermore, although no high temperature combustion zone occurs in the charcoal retort yet the amount of heat required to generate the gas is much less than that for steam-charcoal.

No. 3. Burnt Town Gas treated over Charcoal.

This gas contains more nitrogen and is therefore inferior to (2). Its production would entail cumbersome equipment if the town gas burner and the charcoal-tower were separate units, but it is possible to heat the charcoal tower by gas-fired burners and then to treat part of the gas from the burners over the charcoal. Even so the unit is not so simple as that required for (2).

No. 4. Town Gas treated over Charcoal.

This atmosphere, though its composition is obviously very dependent upon the composition of the raw gas supplied, is normally rich in methane and low in nitrogen. It differs from the previous atmospheres in that during passage over the charcoal one of the equilibrium reactions is not completely " stabilised ", i.e. the methane concentration is relatively in considerable excess of the equilibrium value. This is due to the slow rate of breakdown of methane in the charcoal tower. The gas produced has a high carburising potential but, again due to the slow rate of methane breakdown, it is necessary to preserve this high carbon pressure in order to maintain carburising speed. Such an atmosphere, as generated, is always higher in carburising potential than is required to produce saturated austenite. Therefore, on cases of medium depth, where the steel requires only a fraction of the amount of carbon in the later stages of carburisation compared with the amount it requires in the early stages, the uptake of carbon cannot be regulated easily by control of the ingoing gas composition. The second stage of the process—the " diffusion " period—must then be controlled by reducing the flow of gas to as low a flow as practicable so that the amount of available carbon is lowered.

Type (B).

This type includes all these atmospheres which are not stabilised over charcoal before admission to the furnace. These atmospheres range from those in which the carbon dioxide and water vapour are as low as in those generated over charcoal to those containing appreciable quantities ($[CO_2+H_2O] > 3$ per cent). The former may be produced by the removal of carbon dioxide and water vapour from atmospheres such as burnt town gas by suitable scrubbers. For carburising installations of normal size such equipment is rather cumbersome. Another method of preparation is to run air and a fuel gas over a catalyst, other than charcoal, at a temperature near 1,000 degs. C. This second method differs from the charcoal treatment in two ways :

1. There is no consumption of the catalyst. However, periodic replacement is required.
2. No carbon may be picked up by the gas from the catalyst, hence the ratio of air to raw gas must be carefully controlled. If the air to gas ratio is high there is insufficient carbon present to convert all the oxygen present into carbon monoxide and a decarburising gas is produced ; on the other hand, if the air to gas ratio is low the catalyst becomes sooted up.

In practice the mixture is run slightly on the sooting side and the carbon has to be burnt off by a short air-blow at intervals of, say, a week.

These atmospheres which contain a few per cent of decarburants must also contain a balancing percentage of reactive hydrocarbons. The parent atmosphere is usually a burnt fuel gas from which the bulk of the water vapour is first condensed out and then the remaining few per cent are taken out by driers. A typical burnt town gas would contain, after this treatment, approximately 4 per cent of carbon dioxide, with carbon monoxide, hydrogen, and approximately 70 per cent of nitrogen. After the addition of hydrocarbon the atmosphere is " unstabilised " and further reaction must occur in the furnace chamber before a suitable mixture is produced.

8. THE SELECTION OF FURNACE AND GAS GENERATOR.

It would be absurd to state that the design of furnace and of generator should be of a certain type for all carburising installations. Each case has to be decided on such considerations as depth of case required, the normal size of pieces to be treated, output required, the advisability of tumbling the work, variability of requirements, etc. Such considerations decide the type of furnace, and the type of furnace decides the type of gas generator best suited for the job. However, as an example, the usual treatment desired is the carburisation of pieces which, first, may not be tumbled, and, second, are not readily treated in a continuous furnace, i.e. the furnace is to be a batch type handling a stationary charge.

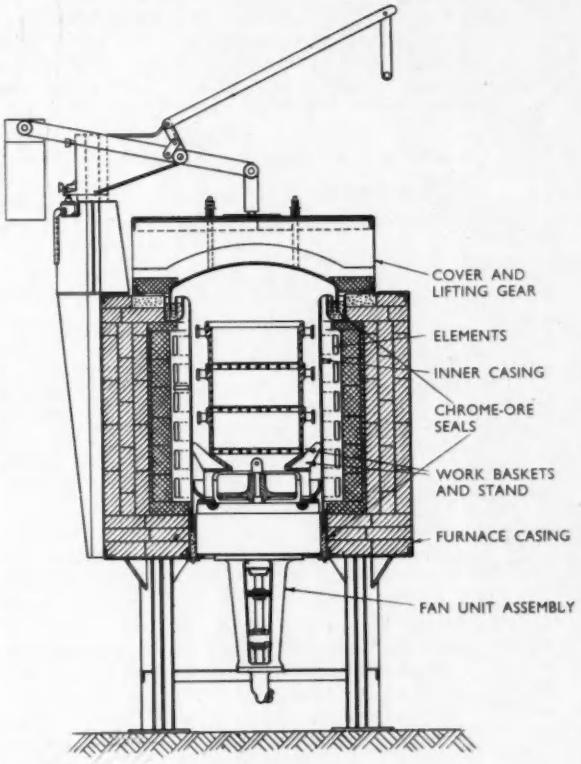


Fig. 9.—Carburising furnace.

The object is to design a furnace so that the best results are to be obtained when treating the worst type of charge, i.e. "close-packing", and to obtain the best results with any type of carburising atmosphere, e.g. "soot-forming". The generator must need little attention, it must produce a consistent gas, capable of carburising under non-ideal conditions and, above all, it must be such that the heat-treatment may be simple and flexible.

The Furnace:

1. High-speed gas circulation is necessary in order:
   (*a*) To obtain uniformity of temperature throughout the charge.
   (*b*) To ensure that fresh gas is supplied over all surfaces to be carburised.
   (*c*) To ensure that the potentially soot-forming gas, which is being supplied, is rapidly diluted.
   (*d*) To ensure that the gas is of uniform composition throughout the charge.
2. The treatment chamber must be effectively sealed against air ingress if control over the atmosphere in the chamber is to be maintained.
3. The transition stage wherein the ingoing gas passes from the inlet pipe, at room temperature, to the hot gas stream should be as short as possible. By so doing, the risk of soot deposition from the hydrocarbons at intermediate temperatures is minimised.
4. The furnace must be such that charging and discharging may be carried out rapidly. The charge must be sufficiently protected from air infiltration during transfer to the cooling chamber. By these means decarburisation of the charge after treatment is avoided.

A furnace designed to meet the above requirements is shown in fig. 9, the charge volume being 4 cu. ft. The various points called for in design have been met in the following manner:

1. Gas circulation: The arrangement of the work containers and supporting stool enable the fan in the base to provide a directional flow of gas at high velocity over the work. The speed of the gas flow inside the furnace is such as to dilute the incoming gas at least 100 times.
2. The treatment chamber is enclosed by a sand seal at the top into which both the inner cylindrical lining and the hood fit.
3. The inlet tube to the furnace is water-cooled.

When carburising liquids of the type previously described are used, the inlet is through the furnace door.

The Generator:

1. The gas generated must be free from decarburants (CO_2, H_2O, O_2).
2. The "carrier" gas must carburise to a fixed carburising potential, preferably hypo-eutectoid, e.g. 0·6 per cent carbon so that:
   (*a*) Control of the carbon content of the case, can be effected easily, i.e. by addition of a suitable hydrocarbon.
   (*b*) The rate of flow of gas through the furnace can be increased indefinitely without excessive soot formation.
3. The gas must carburise rapidly.
4. Generation and quality of gas must be easily controlled.

It has already been shown that mixtures of carbon monoxide and hydrogen free from water vapour and carbon dioxide carburise rapidly. Considering the possible alternative types of gas generators together with the type of atmosphere they produce, it appears that atmospheres in the class "charcoal-treated", are to be preferred. Of the atmospheres in this class:

1. Steam-charcoal is expensive.
2. Air-charcoal contains only a few per cent hydrogen, and charcoal consumption is high.
3. Neat town gas treated over charcoal will contain such proportions of methane that its carburising potential, though high, cannot be controlled.
4. Air + town gas, treated over charcoal, though containing more nitrogen than either steam-charcoal gas or treated town gas, nevertheless contains, in addition to nitrogen, carbon monoxide and hydrogen only, in comparable proportions. It may be controlled so as to contain less than 2 per cent methane, and hence its carburising potential may be varied and controlled by the addition of hydrocarbon prior to its entering the furnace. The consumption of charcoal is very low.

The generator, shown diagrammatically in fig. 10, was designed to treat mixed volumes of air and gas so as to produce a gas of approximate composition.

The maximum control temperatures at which the retort could be controlled was 1,100 degs. C. and provision was made for filtering and cooling the issuing gas. Charcoal level is maintained by means of the supply hopper.

GAS QUALITY.

The variation in the composition of town gas between different localities makes some difference in the optimum ratio of air/gas at which the mixed gases are supplied to the charcoal chamber. However, the following results indicate the important characteristics of the generator:

(a) Air/gas ratio.

This unit was designed to produce 300 cu. ft. of a suitable carrier gas, i.e. a mixture of CO, H_2, and N_2 containing $CH_4 < 2$ per cent and $CO_2 < 0{\cdot}5$ per cent. The ratio of air/gas necessary to obtain this result was 5/4.

Control Temp. ° C.	Air/Gas Ratio	Flow cu.ft./hr.	Percentage			
			CO_2	CO	CH_4	H_2
1050	1/1	300	0·4	17·8	5·9	36·2
1050	5/4	300	0·6	20·2	1·4	39·5

(b) Variation of quality with flow.

(Temperature of charcoal = 1,050 degs. C.)

Air/Gas Ratio	Flow cu.ft./hr.	Percentage			
		CO_2	CO	CH_4	H_2
1/1	100	0·0	18·9	2·1	45·5
	140	0·2	19·8	1·4	43·5
	175	0·2	20·5	1·4	41·5
	200	0·4	19·9	2·2	39·3
	220	0·4	18·7	2·3	34·3
	250	0·4	18·8	3·1	35·4
5/4	100	0·2	21·2	0·0	40·5
	175	0·2	20·7	1·7	38·6
	200	0·4	22·1	1·7	36·0
	220	0·6	19·5	1·1	37·7
	250	0·4	20·4	1·1	36·9
	300	0·6	20·2	1·4	39·5

Judged on these results the gas was suitable for use at flows up to 300 cu. ft./hr. at an air/gas ratio of 5/4.

(c) Consistency.

In order to ascertain what the inherent fluctuation in gas quality was over a length of time comparable with normal carburising periods, the air/gas setting was kept constant at 1/1, the flow at 250 cu. ft./hr. and the control temperature at 1,050 degs. C. The gas was then analysed over a period of twelve hours.

The results were as follows:

Time (hrs.)	0	3	6	9	12	Average
Per cent						
Hydrogen	36·8	35·6	45·6	44·4	42·6	41·0
Carbon Monoxide ..	17·2	17·8	18·6	17·0	18·0	17·9
Methane	1·6	2·2	1·6	1·8	2·0	1·8
Carbon Dioxide ..	0·2/0·4	0·2/0·4	0·2/0·4	0·2/0·4	0·2/0·4	0·30

Taking a mean value for the carbon monoxide and carbon dioxide figures the ratio $\frac{p_2CO}{pCO_2}$ thus obtained is 10·6 which, according to fig. 2, is the ratio in equilibrium with an 0·35 per cent carbon steel at 900 degs. C.

(d) Carburising potential.

Fig. 11(*b*) is a photomicrograph of the case obtained on a 3 per cent nickel carburising steel which formed part of a full charge of mild steel

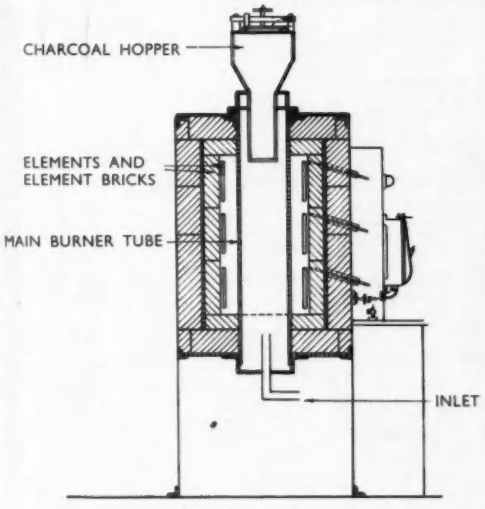


Fig. 10.—Charcoal tower.

treated for three hours at 900 degs. C. in a flow of 75 cu. ft./hr. This carbon content represents the lower limit of the carburising potential of the atmosphere produced under those conditions of temperature and flow under which the generator unit was operated. This test also indicated that the sealing of the furnace was effective at a flow of 75 cu. ft./hr.

(e) Effect of further drying.

In fig. 11(*a*) is shown the case of similar steel treated under similar conditions as obtained

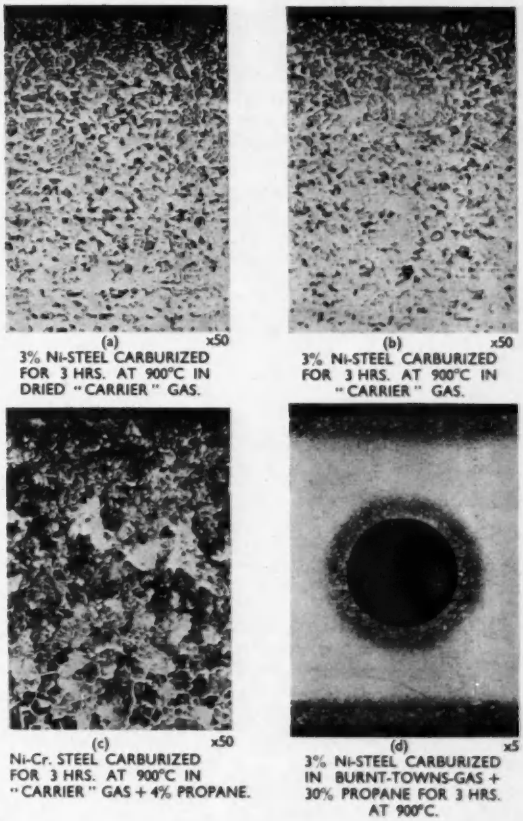

(a) x50
3% Ni-STEEL CARBURIZED FOR 3 HRS. AT 900°C IN DRIED "CARRIER" GAS.
(b) x50
3% Ni-STEEL CARBURIZED FOR 3 HRS. AT 900°C IN "CARRIER" GAS.
(c) x50
Ni-Cr. STEEL CARBURIZED FOR 3 HRS. AT 900°C IN "CARRIER" GAS + 4% PROPANE.
(d) x5
3% Ni-STEEL CARBURIZED IN BURNT-TOWNS-GAS + 30% PROPANE FOR 3 HRS. AT 900°C.

Fig. 11.—Experimental carburising treatments in recirculated atmospheres.

previously except that the carrier gas was dried over silica gel. The difference in result is not appreciable.

(f) Hydrocarbon addition required for maximum carburising speed.

In fig. 11(*c*) is shown the case obtained in a nickel-chromium carburising steel (2·18 per cent

Ni, 1·10 per cent *Cr*) treated, as part of a full charge, for three hours in 75 cu. ft./hr. of carrier gas + 4 per cent of propane.

The above results indicated that the gas generator would supply a carrier gas, suitable for carburising, at flows up to 300 cu. ft./hr. By the controlled addition of amounts of propane, up to 5 per cent, complete control over the carbon content of the case could be achieved.

EFFICIENCY OF FAN.

The fan efficiency was tested by treating a test-piece consisting of a $\frac{3}{8}$-in. diameter rod with a $\frac{1}{8}$-in. hole drilled diametrically in a full charge at 900 degs. C. The atmosphere supplied was burnt town gas + 30 per cent propane. The charge was sooted but carburisation had occurred at a point half-way along the drilling (fig. 11(*d*)).

In all the above treatments, after the desired period of carburising had been attained the baskets were covered and transferred rapidly to a water-cooled cooling chamber and allowed to cool under town gas. The sealing of this chamber was of a similar type to that of the furnace.

The equipment described above was designed to obtain the best performance and flexibility from both the furnace and generator. When charges are such that they may be treated in a gas of one carburising potential during the initial period and in a gas of a second carburising potential during the diffusion period, then the use of liquids as a means of supplying these gases should be seriously considered. Liquids of various carburising strengths are available and two may be selected, such as to provide the initial and the "diffusing" atmospheres respectively. In the case of those particular liquids described, the cost per cubic foot of gas produced is greater than is the cost of the charcoal-treated gas and, of course, there is no easy means of varying the carbon potential during carburising between that of the first liquid and that of the second. However, the simplicity of the drip-feed method makes the process attractive, especially for small furnace installations.

Remote Supervisory Control of Power Distribution Systems

By A. Baker.

G.E.C. Telephone Works, Coventry.

The control requirements of a power transmission network are discussed in broad outline. Principles of operation of various types of remote supervisory control are briefly described and reference is made to systems utilising existing power lines to convey supervisory signals, also to systems requiring additional pilot wires.

The remote supervisory control systems employed on the network of the Derby & Notts Electric Power Company are described in detail. The degree of flexibility in remote control and supervision attainable by such systems is indicated and their many other possible applications are discussed.

INTRODUCTORY.

CENTRALISED control is essential for the efficient handling of an electricity undertaking in which plant is situated at many different points throughout the area. A supply network for the transmission and distribution of power from a central generating station is typical of such an undertaking, and considerable administrative advantages are achieved by the unification of control. By employing a system which combines both supervision and remote control of outlying plant, maximum operating efficiency can be obtained as the central station is always fully and instantaneously informed of the conditions and changes throughout the network. In addition to operating advantages, economies in personnel can be achieved as the system can be applied to the control of unattended stations.

REQUIREMENTS.

The requirements for the centralised control of equipment situated at one or more points will vary considerably and be affected by the geographical layout of the network and the control plan to be adopted. In no two networks will conditions be

identical, but the inherent flexibility of the system enables the most stringent demands and complex requirements to be fulfilled. This fact is amply illustrated by the wide application of supervisory control systems, both at home and overseas, for undertakings ranging in size from a single substation to the complicated networks found in the British National Grid.

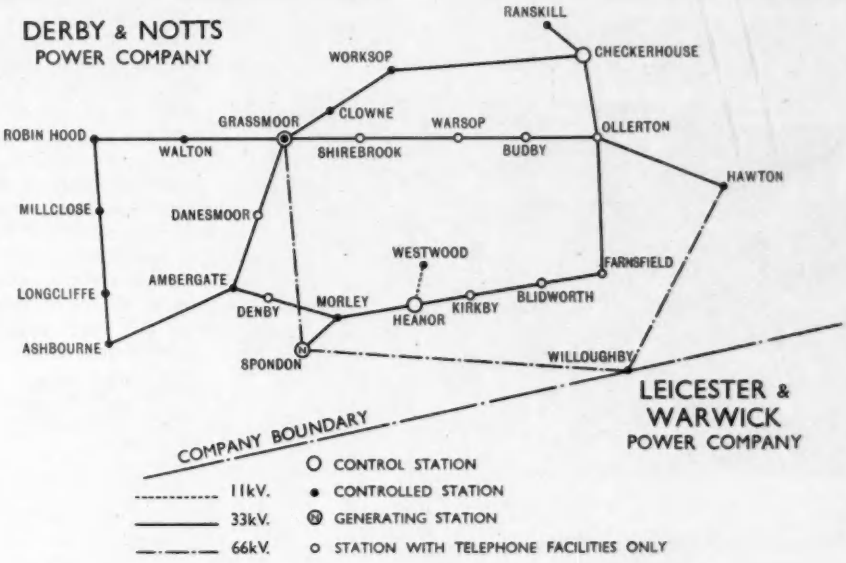


Fig. 1.—Part of the network of the Derby and Notts Power Company.

The control requirements of a power undertaking operating a transmission network may be summarised as follows :

(*a*) Facilities enabling the switchgear at the distant substations to be operated from the control station.

(*b*) Automatic indication at the control station of the position or condition of switchgear at the substations.

(*c*) Facilities enabling the control station to obtain readings of substation currents and voltages.

(*d*) Telephone communication.

The supervisory control systems employed to provide these services differ in certain details, depending upon the signalling channels and the nature of the power plant to be supervised, but the principles of operation are basically similar. At the control station a control panel is provided on which the substation plant is represented by groups of keys and coloured lamps arranged in the form of a mimic diagram of the undertaking. From the control panel the engineer can control and supervise plant at the substations while the lamps in the mimic diagram provide continuous indication of conditions over the whole undertaking.

All the facilities normally required can be provided over only two pilot wires linking the substations to the control station, but, should a larger number of wires be available, the amount of supervisory equipment required can be reduced. The apparatus and methods of signalling have been well proved in the field of telecommunications and ensure a control system possessing a high degree of reliability in service.

COMMUNICATION CHANNELS.

The method adopted to provide the requisite communication channels is dependent upon the conditions in a particular network, and consideration of a large number of factors is essential to the planning of the most suitable scheme. Where electric power cables are laid underground, pilot cables are generally laid alongside and, in the case of overhead power distribution systems, pilot cables are usually carried on the same towers as the H.T. line.

If the pilot cable is exposed to the electromagnetic and electrostatic fields of the power lines, provision is made for the protection of

terminal equipment and operating personnel. This is provided by the inclusion of protective equipment at each termination of the pilot cable, comprising drainage coils, carbon spark-gap arrestors, and suitably insulated line transformers effectively isolating the terminal equipment from the pilot cable.

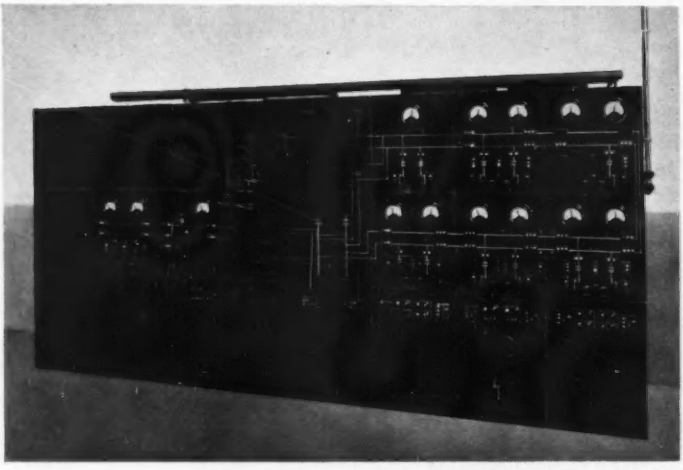


Fig. 2.—Grassmoor control panel.

Another method, which dispenses entirely with separate pilot cables, is the use of carrier currents superimposed on the power lines. Such carrier circuits can be used for remote supervisory control signalling and may also be used for telephone communication by modulating the carrier currents with the speech currents at one end and demodulating at the other. At the ends of each section of the power line suitable devices are inserted for the separation of the carrier currents from the low-frequency power currents.

As the provision of a carrier circuit superimposed on the power lines requires only the addition of terminal carrier equipment, and requires no auxiliary line plant other than the separating devices, this method can be employed with considerable economic advantage where the stations involved are widely separated. In addition, the circuit so provided is an inherently reliable channel, as the power lines themselves have a very high factor of safety.

PRINCIPLES OF OPERATION.

For remote supervisory control the substation switchgear is arranged for solenoid or motor operation, controlled by interposing relays which can be operated from the supervisory equipment. All supervisory operations are effected by the transmission over the signalling channels of trains of impulses by means of which standard telephone type relays are operated, which in turn control the operation of multi-point rotary selectors. By the use of predetermined trains of impulses any required circuit breaker or other controlled plant can be selected and subsequently operated by the transmission of further signals from the control station. To obviate the possibility of false operation due to the mutilation of signal impulses or through any other cause the system incorporates a check-back feature. In order to confirm the accuracy of selection before any further operation is carried out, corresponding trains of impulses are returned to the control point. In this manner inadvertent operation of the wrong point is prevented.

The same signalling channels and selective equipment provide for the continuous indication at the control station of substation plant. In order that the indications received at the control station shall provide an accurate moment-to-moment picture of the state of the network, a signal is transmitted to the control station if the condition of any plant is changed other than by supervisory control. For example, if a circuit breaker trips, due to a fault condition, auxiliary contacts of the breaker initiate operation of the supervisory circuits at the substation and the transmission of a signal to the control station.

CONTROL AND INDICATION.

Operation of the equipment may be illustrated by considering the case of a substation circuit breaker which is in the " open " position. On the control panel this circuit breaker is represented by a select key and three lamps coloured green, white and red respectively. With the breaker in the " open " position the green lamp will be glowing, and in order to close the breaker the control engineer first operates the corresponding select key. The supervisory apparatus at the control station operates to select the wanted substation and then the required breaker at that substation. As soon as the circuit is correctly prepared, the check-back signals from the substation cause the white lamp adjacent to the operated key to glow, indicating that the operation

can now be performed. To close the circuit breaker, the control engineer now depresses a separate operating key on the control panel to initiate the transmission of the appropriate operating signal. As soon as the operation is complete, a signal is returned to the control station indicating the new position of the circuit breaker, the green lamp is extinguished and the red lamp glows. The select key is then returned to the normal position which causes the white lamp to be extinguished.

Should the breaker at the substation trip due to a fault condition or any other cause, the lamp indication on the control panel changes over from red to green and the new lamp indication flashes. At the same time an alarm bell rings to give warning to the control engineer that an uncontrolled operation has taken place, the flashing lamp indicating the affected point. By operation of a key provided on the control panel, the alarm bell is silenced and the flashing lamp changed to a steady indication on acknowledgment of the alarm indication.

In the foregoing, specific reference has been made to the control and indication of a circuit breaker, but the same selective equipment provides remote control for other plant at the substations in a similar manner, the method of indication and the control arrangements fitted on the control panel depending upon the nature of the substation plant to be supervised.

Metering.

Different methods of obtaining remote meter readings of currents and voltages at the substations can be employed and the scheme adopted depends largely upon the communication channels available. Instrument readings in the substations are reproduced on meters at the control station and a process of selection similar to that described for the control of switchgear enables any meter to be selected for reading.

The simplest system is to employ auxiliary current and voltage transformers at the substations which are selected as required and connected directly to the appropriate control station meters over the pilot wires. This method is affected by the characteristics of the line and, generally speaking, is only operated over comparatively short distances. To enable remote metering and supervisory control to be operated over the same channel, impulse systems have been developed whereby meter readings are transmitted in the form of trains of impulses, the frequency of impulsing being proportional to the originating meter reading.

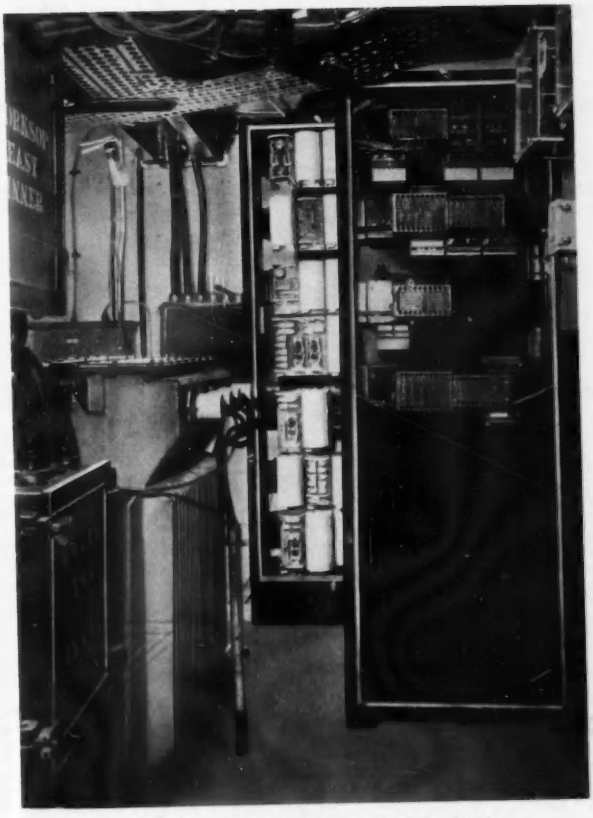


Fig. 3.—Grassmoor supervisory control cabinets.

The Derby and Notts Electric Power Company.

A power network which employs a number of remote supervisory control systems is that of the Derbyshire and Nottinghamshire Electric Power Company. The network serves an area of some 1,700 square miles and includes a large generating station at Spondon. Part of the undertaking's transmission system comprises a number of interconnected 33 kV ring mains and 66 kV transmission lines. This section of the network, together with the location of supervisory control systems, is shown in fig. 1.

From Grassmoor, two remote supervisory control systems provide control

in tandem of six substations forming the Ashbourne ring, namely Walton, Robin Hood, Millclose, Longcliffe, Ashbourne and Ambergate, and also control in tandem the substations at Clowne and Worksop. At Spondon generating station three supervisory control systems provide control of switchgear at Morley, Grassmoor and Willoughby respectively, the last two systems being operated on carrier links provided over the 66 kV power lines. Other supervisory systems provide control of Westwood substation from Heanor and control of two substations at Ranskill from Checkerhouse.

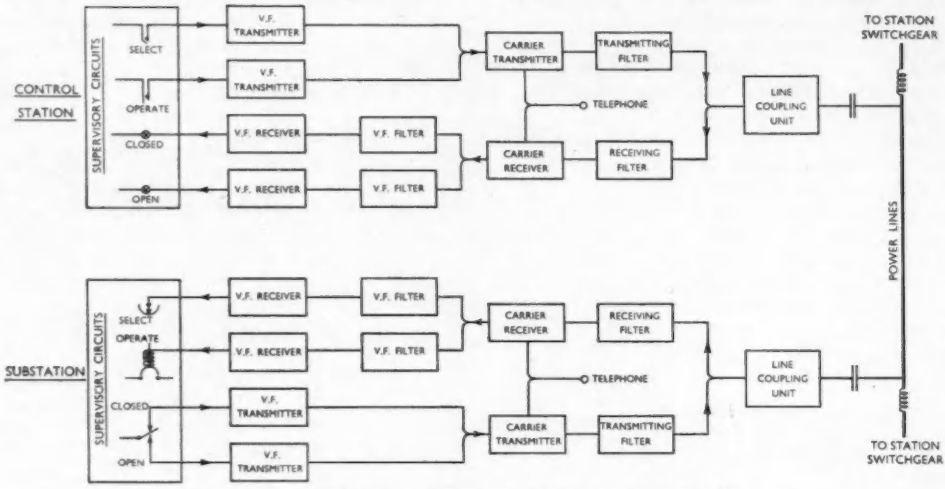


Fig. 4.—Principle of voice frequency and carrier link operation.

In addition to remote supervisory control facilities, telephone communication is provided by party lines and arrangements are made by which stations on any part of the network may be interconnected.

To illustrate different applications of remote supervisory control, certain of the systems will now be considered in greater detail.

Heanor-Westwood.

The first application of remote supervisory control by the Derby and Notts Company was for the control from Heanor of Westwood substation. Heanor is situated on a 33 kV ring main and feeds Westwood at 11 kV. With the substation normally unattended and situated in a somewhat inaccessible position, considerable advantages were gained by the application of a supervisory system for the remote control of Westwood.

A three-pair underground cable is laid between Heanor and Westwood to provide the supervisory signalling channels, one pair being used for impulsing from Heanor, one pair for the check-back signals, and the remaining pair for the actual operating impulse. A telephone circuit is provided over one of the pairs, which is automatically made available for impulsing

Fig. 5.—Supervisory control cabinets and carrier sets at Spondon.

should any change in switchgear position require to be made or indicated during conversation.

At Heanor, a control panel is provided with the Westwood switchgear represented by groups of keys and lamps arranged in the form of a mimic diagram of the substation plant. The control panel also carries a number of meters for the reading of voltages and currents in respect of each outgoing feeder from Westwood. The readings are obtained on demand at Heanor, the pilot wires being connected to selected auxiliary current and potential transformers to obtain the appropriate readings.

For the operation of the supervisory equipment a 50-volt D.C. supply is required and at each station a storage battery is provided, trickle-charged by a mains-operated rectifier unit.

Grassmoor-Ashbourne Ring.

The supervisory control system as used on the Ashbourne ring employs voice-frequency signalling, a method which requires only two pilot wires for operation.

To provide the necessary channels of communication to effect the remote control from Grassmoor of plant at the substations, the stations on the ring are interconnected by a six-pair pilot cable suspended from a catenary wire attached to the overhead power transmission line supports. Only one pair of the pilot cable is required for supervisory control signalling, and, to improve the transmission characteristics of the circuit, one quad of the pilot cable is loaded. The other pair of the loaded quad is utilised for telephone communication, leaving the remaining pairs of the cable for other facilities such as feeder protection.

At Grassmoor control room a panel is provided made up of a number of small sections, each section representing one substation and the whole forming a line diagram of the ring. A view of the control panel is shown in fig. 2.

Four distinct signalling channels are provided by the use of four frequencies in the voice-frequency range, two being used for each direction of transmission. Thermionic valve voice-frequency transmitters and receivers are employed, and the various signalling channels are separated by the use of tuned filters at both the sending and receiving stations. Supervisory control signalling is effected by trains of impulses as previously outlined, but, on this system, D.C. impulses produced in the supervisory equipment are converted by the voice-frequency equipment into impulses of alternating current at a voice frequency on the appropriate signalling channel. At the receiving terminal, the voice-frequency impulses are translated by the voice-frequency receiving circuits and transmitted to the associated supervisory circuits to actuate the relay and selector equipment.

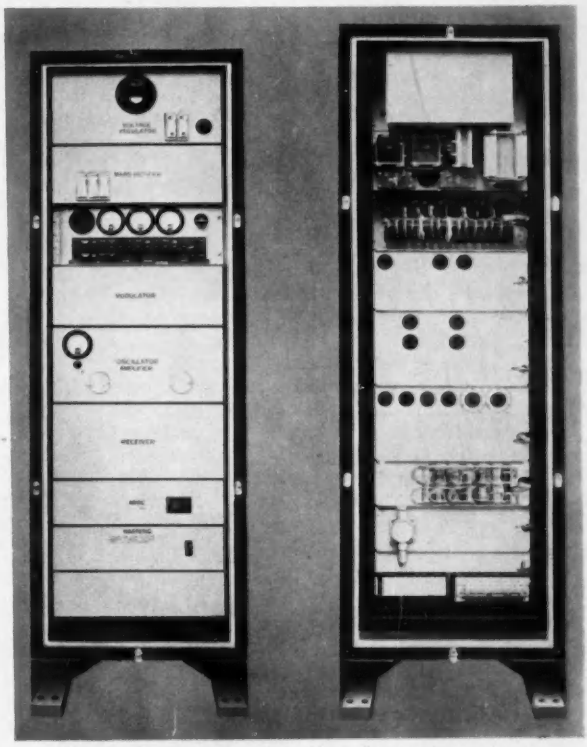


Fig. 6.—Power-line carrier cabinet, front and rear views.

A view of the control cabinets at Grassmoor is shown in fig. 3. The relay and selector equipment is designed to operate on a 50-volt D.C. supply and the voice-frequency equipment uses the same supply for the valve filament circuits with a separate 125-volt D.C. supply for the anode circuits.

A common telephone circuit, on a separate pair of the pilot cable, links Grassmoor with each of the substations for party-line working. At the control station, the telephone equipment, in-

cluding switching and signalling apparatus, is concentrated on the control engineer's desk, while at each substation a wall-pattern magneto telephone is provided. Telephone circuits linking stations on other sections of the network terminate on the control engineer's desk at Grassmoor and stations on different circuits can be interconnected.

SPONDON-WILLOUGHBY.

A further application of supervisory control systems is illustrated by the scheme in operation for the control of switchgear at Willoughby from the generating station at Spondon. On this system the necessary signalling channels are obtained by superimposing carrier currents on the 66 kV power lines. The principles employed are shown in schematic form in fig. 4.

A separate carrier frequency is used for communication in each direction, both frequencies being superimposed on the same pair of power lines. The outgoing frequency generated in the carrier set passes via concentric cable and is then injected into the power circuit by means of capacitors suitably designed to withstand the line voltage. These capacitors offer a negligible impedance at the carrier frequencies, but a very high impedance at the power frequency, and, with the associated protective equipment, effectively isolate the carrier set from the line voltage. To prevent leakage of the high-frequency currents back into the station equipment, choke coils are inserted on the station side of the coupling capacitors. These coils are tuned to offer a negligible impedance at the power frequency, but a very high impedance at the carrier frequencies.

The supervisory control equipment associated with the carrier links is as described for the Grassmoor-Ashbourne ring. Fig. 5 shows the supervisory control cabinets and carrier sets at Spondon. D.C. signals generated in the supervisory signalling circuits are translated into impulses of the appropriate voice-frequency signalling channel which in turn modulate the carrier frequency. At the receiving terminal, the modulated carrier frequency passes via the coupling capacitors, filter and protective unit, and concentric cable to the receiving circuits in the carrier set. The carrier signal is demodulated and the voice-frequency component passed on to the voice-frequency and supervisory equipment where the signals are translated back into D.C. to operate the switchgear.

The carrier sets are normally quiescent and carrier current is only transmitted when communication is required, the carrier frequencies employed being 110 kc/s and 170 kc/s. Front and rear views of a typical carrier cabinet with doors removed are shown in fig. 6.

At Willoughby, automatic telephone equipment is installed to provide connection between Spondon, Willoughby and stations on the Hinckley-South Croxton group of the adjoining power network operated by the Leicestershire and Warwickshire Electric Power Company. Connections are established by dialling

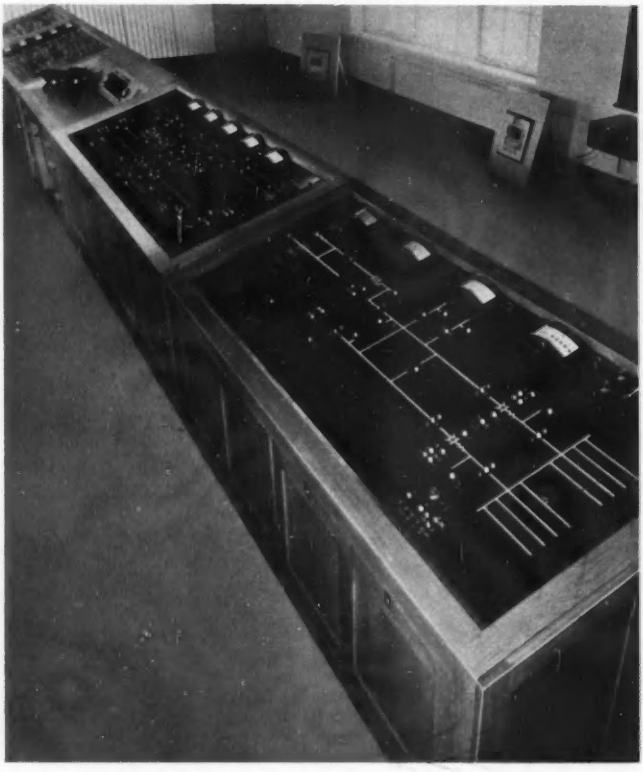


Fig. 7.—A general view of the engineer's desk and control panels at Spondon.

the number of the wanted station and the dial impulses are transmitted over the carrier link as interruptions of the unmodulated carrier frequency.

Some of the switchgear at Willoughby substation is part of the network operated by the Leicestershire and Warwickshire Electric Power Company, and arrangements are provided for alternative control of this plant from either Spondon or Hinckley. Operation of a key on the control engineer's desk enables Spondon to assume control of the switchgear. Indication that Spondon has taken over is displayed at Hinckley for information of the Leicester and Warwick controllers. Similarly, depression of a key at Hinckley regains control for Leicester and Warwick and results in indications at Spondon. Fig. 7 shows the engineer's desk and control panels at Spondon and fig. 8 a near view of the control panel for the Grassmoor section.

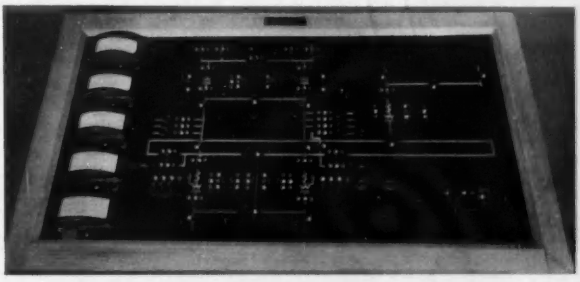


Fig. 8.—A near view of the control panel for the Grassmoor section.

The system by which switchgear at Willoughby is controlled from Spondon generating station, over a carrier circuit on the 66 kV line, has been extended to Hawton substation over a similar link. This carrier circuit is at present used only for telephone communication, but will eventually form part of a tandem system providing remote supervisory control of Willoughby and Hawton from Spondon.

OTHER APPLICATIONS.

The foregoing has given an outline and a description of the fundamental methods of the operation of remote supervisory control systems, together with details of several typical installations as applied to the control and supervision of plant on an electricity supply network. The flexibility of the system, however, enables centralisation of control to be obtained on other undertakings such as traction systems, water systems, sewage-disposal plants and the like. In brief, any plant which can be arranged to be electrically operated may be remotely controlled and supervised.

ACKNOWLEDGMENTS.

Acknowledgments are due to the Derbyshire and Nottinghamshire Electric Power Company and Balfour, Beatty & Co. Ltd., for their kind permission to publish the information contained in this article.

Practical Aspects of Cold Cathode High-Voltage Lamps in Decorative and General Lighting

By C. DYKES BROWN, A.M.I.E.E., and K. S. MORRIS, M.S.I.A.
Illuminating Engineering Department.

Fig. 1.—An effective indirect lighting scheme in the first-class lounge of M.S. Oranje in which triple lines of Osram cold cathode fluorescent lamps are used.

INTRODUCTION.

THE introduction of coloured fluorescent lamps of the cold cathode type in this country in 1933 opened up a new field of decorative lighting, largely on account of their high efficiency and easy adaptation to special designs. They were soon used effectively in ballrooms, restaurants and in public rooms on ocean-going liners, to mention only a few applications. Since the war the demand for these lamps has considerably increased, not only for decorative purposes, but in many different situations, including commercial and industrial buildings, and they are now considered in the same category as the more conventional sources of light. This increase in popularity can be attributed in some measure to the introduction of self-contained lighting units, incorporating the lamps and transformers and the development of a range of white lamps suitable for general lighting. In this article the authors describe the use of Osram cold cathode fluorescent lamps in present-day practice and refer to some of the practical aspects involved.

COLD CATHODE FLUORESCENT LAMPS.

The theory and technical aspects of high-voltage fluorescent lamps have already been described in detail elsewhere, and for the purpose of this article only a brief reference will be made here to their construction and operation.[1] Cold cathode lamps in general use in this country are tubular in form and have an outside diameter of about 20 mm. The electrodes, one of which is sealed into the lamp at each end, are cylindrical in shape and about 2 ins. long ; they are usually made of nickel or iron. The inside surface of the lamp is coated with a fluorescent powder which becomes luminescent when excited by the short wave radiation from the discharge through the gas filling. As can be seen by reference to Table 1, a discharge through low-pressure mercury vapour is used to excite certain powders to produce a number of colours which are suitable for lighting purposes ; colours of a warmer tone are obtained by exciting fluorescent powders in a neon discharge.

The majority of cold cathode lamps have a lighting length of 8 ft. 6 ins., but they are also made in various lengths or shapes to meet the requirements of the particular scheme or design.

It is sometimes advantageous to use lamps up to 18 ft. in length for decorative fittings, as described later, but for manufacturing reasons their shape must be such that it can be encompassed by a rectangle 9 ft. 6 ins. by 2 ft. 9 ins. Because the electrode losses are constant, irrespective of the length of the light source, short lamps are less efficient than long lamps and are used only when the situation demands. The electrodes can be set at any desired angle relative to the luminous portion of the lamp, but in most installations it is usual for them to be either straight on to the lamp, as in fig. 2 (*a*), or turned back parallel, as in fig. 2 (*b*). This latter arrangement is usually adopted when continuity of light is required, such

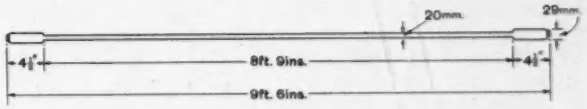


Fig. 2.—(*a*) Dimensions of a standardised cold cathode lamp with straight-on electrodes.

(*b*) Dimensions of a standardised cold cathode lamp with electrodes turned back.

TABLE 1

PHOTOMETRIC CHARACTERISTICS OF COLD CATHODE LAMPS.

Colour of Lamp	Gas Filling	Fluorescent Powder	Lamp Efficiency in lumens per watt at 100 hours	Lamp Efficiency in lumens per watt, Average over 10,000 hrs.	Surface Brightness C/sq. ins. at 100 hours and 60 mA working (*b*)
Daylight	Argon and Mercury	Calcium Halophosphate	40	31	1·88
Intermediate White	„	„	40	31	1·88
Warm White ..	„	„	40	31	1·88
Cerise	„	Cadmium Borate	28	18	1·29
Deep-Blue ..	„	Calcium Tungstate	16	10	0·77
Sky-Blue ..	„	Magnesium Tungstate	31	22	1·48
Bright-Green ..	„	Zinc Silicate	64	46	3·04
Gold	Neon	„	20	20	1·1
Red (*a*)	„	—	13·5	13·5	0·75

NOTES.

(*a*) The red lamp is not coated with a fluorescent powder.
(*b*) The surface brightness is approximately doubled for 120 mA working.

as in an indirect cornice lighting system. Adjacent lamps can then be butted as close as half an inch to each other.

The voltage required to operate the lamps is proportional to their length and depends on the gas filling. In addition to the voltage drop along

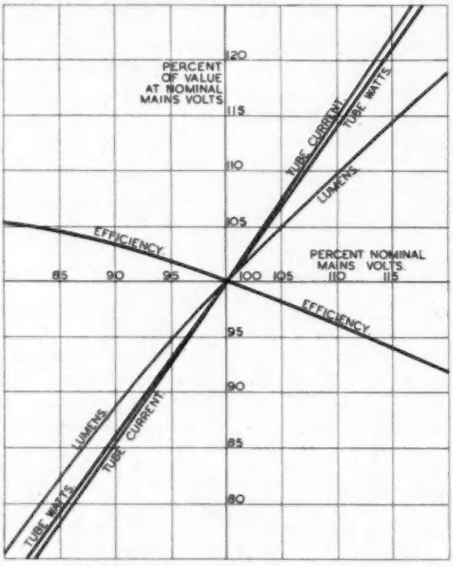


Fig. 3.—Effect of variation of mains voltage on the characteristics of mercury-filled cold cathode lamps.

the luminous portion a further voltage drop also occurs at the electrodes. The voltage across any length of lamp can be readily calculated by reference to Table 2. The figures shown refer to the normal running voltage and do not allow for the higher voltage necessary to initiate the discharge. This latter figure is about 50 to 80 per cent more than the running voltage and is referred to later.

As an example, the running voltage across a mercury-filled lamp operating at 120 mA with a lighting length of 8 ft. 6 ins. and electrodes arranged as shown in fig. 2 (*a*) is $(8\frac{1}{2} \times 52) + 195$, or 650 volts. This allows for the 3 ins. of the luminous portion of the lamp which is normally covered by the electrode boxes. When the electrodes are turned back parallel to the lamp as in fig. 2 (*b*), an allowance of 6 ins. must be made for the extra length of lamp which is non-effective and so the voltage required would be $(9 \times 52) + 195$, or 663 volts.

A simple expression which can be used to calculate the watts taken by any lamp is :

$W_t = 0{\cdot}9\, I_t\, (V_t + V_e)$

where W_t = lamp watts.

0·9 = lamp wave form factor.

I_t = lamp operating current in amperes.

V_t = voltage along luminous portion of lamp.

V_e = voltage drop per pair of electrodes.

OPERATING CHARACTERISTICS.

Prior to 1945, it was the usual practice for cold cathode fluorescent lamps of the type under consideration here to be run at a current of 60 mA. Since the war, however, the current through mercury-filled lamps has been considerably increased and some of the colours are now frequently operated at 120 mA. This has enabled a greater light output to be obtained per unit length of the lamp, with an increase in surface brightness. Neon-filled fluorescent lamps are still operated at 60 mA, principally because of a colour change which is apparent at higher currents with this filling.

TABLE 2

VOLTAGE CHARACTERISTICS OF COLD CATHODE LAMPS.

	Mercury		Neon
Lamp Current ..	60 mA	120 mA	60 mA
Electrode drop in volts (per lamp)	190	195	175
Volts drop per foot of lamp ..	57	52	99

Useful data, including the lumens per foot for individual lamps, are given in Table 3. The deep-blue, bright-green, and red lamps are generally run at a current of 60 mA and may be controlled by a dimmer for colour-change purposes, as referred to later.

The average life of Osram cold cathode lamps may be expected to exceed 10,000 hours, while at 60 mA working an even longer life will be obtained with the mercury-filled types. It is of interest to note that these lamps start instantly they are switched on without the assistance of starter switches and that the long life is not affected by frequent switching or by dimming. The lamps will also remain alight, though at a reduced intensity, should the supply be reduced to as low a figure as 50 per cent of the nominal voltage.

As with the hot cathode fluorescent lamp, the efficiency of mercury-filled cold cathode lamps depreciates to some extent throughout life, but the decrease in light output is spread over a very much longer period. The efficiency of neon-filled lamps remains constant. This means that an installation comprising mercury- and neon-filled lamps, such as white and gold, will provide a slightly warmer tone of light

as the lamps age—a change which is generally acceptable.

When the mercury-filled type of lamp is required for use outdoors or in cold situations, a different gas filling is used which gives better results at the lower temperatures.

The curves in fig. 3 show the effect of variation in mains voltage on the operating characteristics of mercury-filled cold cathode lamps.

CIRCUIT ARRANGEMENTS.

The high voltage necessary to start and maintain the discharge in the lamps is obtained from transformers of the "leakage reactance" type. They are designed to supply the full voltage at no load to enable the lamps to strike and subsequently operate with a reduced voltage as soon as the discharge is established. The lamps are usually interconnected so that a number is in series and operate from one or more transformers. The output voltage of each transformer is determined by the sum of the starting voltages of individual lamps in the circuit, but this is not permitted to exceed 5,000 volts to earth. Some transformers are made with one side of the secondary winding, earthed, while others are constructed with the centre point of the secondary winding earthed.

A range of transformers is available for different lamp loads and many of these are provided with tappings on the primary winding, which can be selected for the particular supply and output voltages required. Typical transformers for 60 mA working are capable of providing an open-circuit voltage up to 7 kV and 10 kV respectively; a tapped 120 mA transformer in general use has a maximum open-circuit voltage of 5 kV. As it is necessary to arrange for suitable accommodation for these when planning lighting schemes, brief details of their dimensions and weight have been given in Table 5. Smaller transformers are also used for the operation of one or two lamps and are frequently used in self-contained lighting units. When assessing the loading of individual transformers it should be

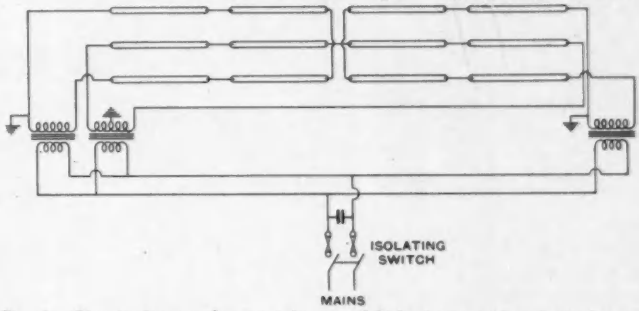


Fig. 4.—Circuit diagram for a triple run of 8.-ft. 6-ins. cold cathode lamps, in which the centre line is neon filled.

TABLE 3
USEFUL DATA FOR PLANNING ILLUMINATION SCHEMES.

Colour	Gas Filling	Lamp Current mA (*a*)	Lumens per foot (*b*)	Approx. Watts per foot (*c*)
Daylight	Argon and Mercury	60 or 120	125	5
Intermediate White ..	"			
Warm White	"		250	9
Cerise	"	60	77	5
Deep-Blue	"	60	43	5
Sky-Blue	"	60	94	5
Bright-Green	"	60	196	5
Gold	Neon	60	128	7
Red	"	60	108	7

NOTES.

(*a*) In addition to the three white lamps, cerise and sky-blue are sometimes operated at 120 mA.
(*b*) Lumens per ft. are the average over 10,000 hours and are irrespective of lamp length.
(*c*) These figures include transformer losses and are based on the assumption that 8-ft. 6-in. lamps are used. They will have to be increased or decreased slightly for installations including shorter or longer lamps.

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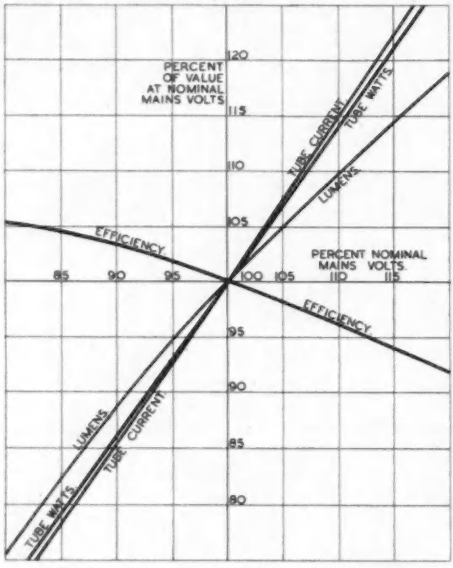

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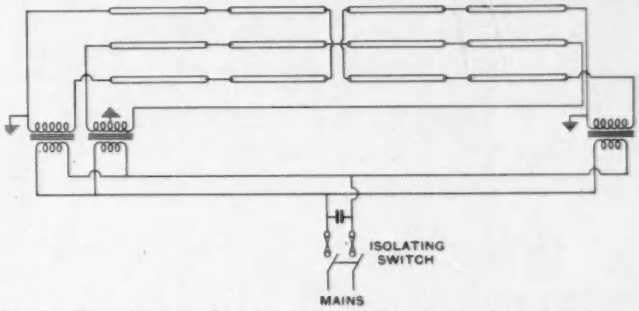

Fig. 4.—Circuit diagram for a triple run of 8.-ft. 6-ins. cold cathode lamps, in which the centre line is neon filled.

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(*b*) Lumens per ft. are the average over 10,000 hours and are irrespective of lamp length.
(*c*) These figures include transformer losses and are based on the assumption that 8-ft. 6-in. lamps are used. They will have to be increased or decreased slightly for installations including shorter or longer lamps.

remembered that the running voltage available will be approximately half the open-circuit voltage.

A typical circuit for a 34-ft. run of triple lamps in which 8-ft. 6-ins. lamps are used is shown in fig. 4. The outer lamps here are mercury filled and the inner one is neon filled. Because of the different operating characteristics of mercury and neon filled lamps they are not interchangeable when an installation has been completed.

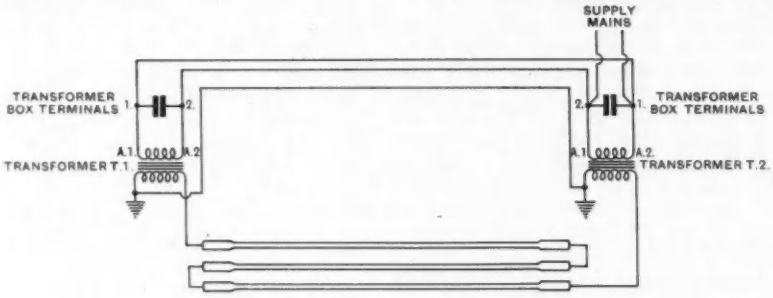

Fig. 5.—Circuit for self-contained cold cathode unit in which all lamps operate at the same current.

TRANSFORMERS IN TANDEM.

A circuit which enables two small transformers to be used instead of a single large one is shown in fig. 5. This makes their accommodation easier, especially where self-contained units are concerned, with circuits in which all lamps operate at the same current (see Table 4, column 2). Two similar transformers are connected so that their secondary voltages are 180 degrees out of phase in order to obtain the total voltage required in the lamp circuit. It will be seen by reference to fig. 5 that this is achieved by connecting the same side of the supply to the " start " of one primary winding (A1) and " finish " of the other (A2).

TABLE 4

DATA FOR STANDARD TRIPLE LAMP UNITS EMBODYING STRAIGHT LAMPS.

	Three Mercury-filled Lamps (*a*) at 120 mA	Two Mercury-filled Lamps (*a*) at 80 mA and one Gold Lamp at 60 mA	Two Mercury-filled Lamps (*a*) at 120 mA and one Gold Lamp at 60 mA	Two Mercury-filled Lamps (sky-blue) at 80 mA and one Gold Lamp at 60 mA (*c*)
Reference No.	F 16994	F 16995	—	—
Overall length of unit	9 ft. 10½ ins.	9 ft. 10½ ins.	—	9 ft. 10½ ins.
Visible lighting length per lamp	8 ft. 6 ins.	8 ft. 6 ins.	8 ft. 6 ins.	8 ft. 6 ins.
Average light output of unit over 10,000 hours	6,500 lumens	3,850 lumens	5,400 lumens	3,220 lumens
Overall consumption of unit ..	250 watts	180 watts	236 watts	180 watts
P.F. (*b*)	0·85	0·85	0·85	0·85
Life of lamps	10,000 hrs.	10,000 hrs.	10,000 hrs.	10,000 hrs.
Approximate weight of complete fitting	35 lbs.	35 lbs.	35 lbs.	35 lbs.

NOTES.

(*a*) These are normally daylight, intermediate white or warm white, and the light output stated applies only when these colours are in use.

(*b*) Capacitors are incorporated in the unit to correct the power factor to the value shown in the table.

(*c*) This combination is particularly useful when a reasonably close approximation to daylight is required and there is no objection to a coloured light source.

POWER FACTOR.

With transformers of the type used in cold cathode lamp installations the uncorrected power factor usually lies between 0·3 and 0·5. The self-contained lighting units described in this article incorporate capacitors which raise the overall power factor to at least 0·85. In the larger type of installation capacitors of a suitable value should be connected in parallel with the primary side of transformers or when a number of transformers is controlled by one switch, group correction can be arranged as shown in fig. 4.

DIMMING OF COLD CATHODE LAMPS.

The light output of cold cathode lamps can be effectively controlled by adjustment of the voltage applied to the transformers. This may be achieved either by (*a*) the use of a variable series resistance suitably graded or (*b*) a variable impedance connected in the input side to the transformers.

The former method is satisfactory for mercury-filled lamps, provided that in a large installation all transformers are equally loaded and the length of high-voltage cable is reduced to an absolute minimum. It is also preferable for any capacitors which are used for power-factor correction to be connected in circuit on the mains side of the resistance. With this arrangement the capacity should be reduced as the lamps are dimmed, otherwise a leading current at low power factor would result. When this method is applied with

Fig. 6.—The cocktail bar at the Royal Albion Hotel, Brighton, showing the use of one line each of 60 mA white and gold lamps in a feature designed to be the focal point in the room.

TABLE 5

DIMENSIONS OF TYPICAL TRANSFORMERS.

Type	Normal Secondary Current	Max. open Circuit Voltage	Case Dimensions			Weight lbs.
			Length	Width	Height	
3/60	60 mA	2·5 kV	6½ ins.	6½ ins.	4½ ins.	15
7/60	60 mA	7 kV	9½ ins.	6½ ins.	7½ ins.	36
10/60	60 mA	10 kV	9½ ins.	7½ ins.	7½ ins.	38
Tandem	120 mA	2 kV	6½ ins.	6½ ins.	4½ ins.	16
5/120	120 mA	5 kV	9½ ins.	7½ ins.	9½ ins.	40

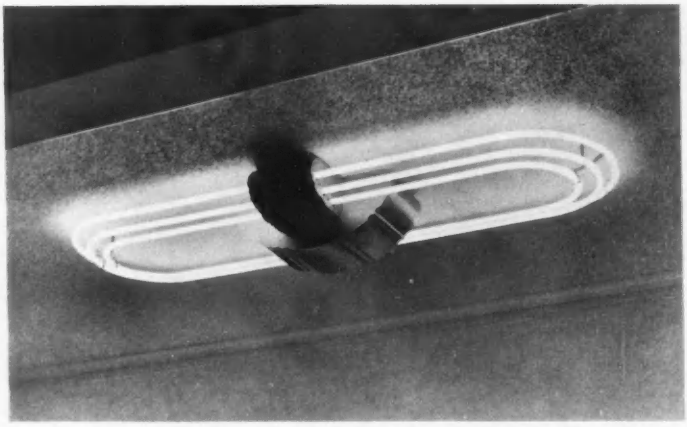

Fig. 7.—Self-contained unit with 60 mA warm white lamps and gilt metalwork.

a correctly graded resistance, it is possible to dim mercury-filled lamps from full brightness almost to extinction.

Circuits involving neon-filled lamps, and mercury lamps in which the transformers would normally be unequally loaded, require special attention if the lamps are to be dimmed satisfactorily. A control system has been developed in which means are provided for controlling the impedance of special chokes, one of which may be installed for each lamp or pair of lamps. The chokes can be designed so that the same current flows simultaneously in all parts of the circuit, being dimmed irrespective of difference in lamp lengths. The impedance of the chokes is varied by a control winding which is connected to a variable D.C. supply. By this method the intensity of neon-filled lamps can be reduced to a very low level.[2]

ARCHITECTURAL AND FUNCTIONAL CONSIDERATIONS.

When contemplating the use of these lamps it is worth considering in some detail the architectural implications and functional aspects of the proposed installation. The quantity of light is easily computed and controlled, but the quality of the light is a more subtle factor and one which may elude even the skilled illuminating engineer, who wishes to match this quality with the architectural atmosphere and the function of the room or building. The main aspects to be observed in this respect are structural features and decorative style which govern the layout, together with the use to which the room is put. Further factors are the colours of the decorations, referred to later, and the degree of importance attaching to the lighting features. These may be required to act as a focal point in the scheme of decorations, such as depicted in fig. 6, or to be totally subservient.

With these lamps excellent opportunities exist for matching the lighting installation to the mood of the interior. For example, high intensities may be obtained with grouped lamps or strongly decorative effects from shaped lamps used either visibly, in glass or metal features, or in cornices.

Decorative self-contained units, such as are shown in fig. 7, provide a soft, restful light for places of entertainment and afford endless opportunities for the designer to use the many possible shapes that can be manufactured, together with the various colour combinations available.

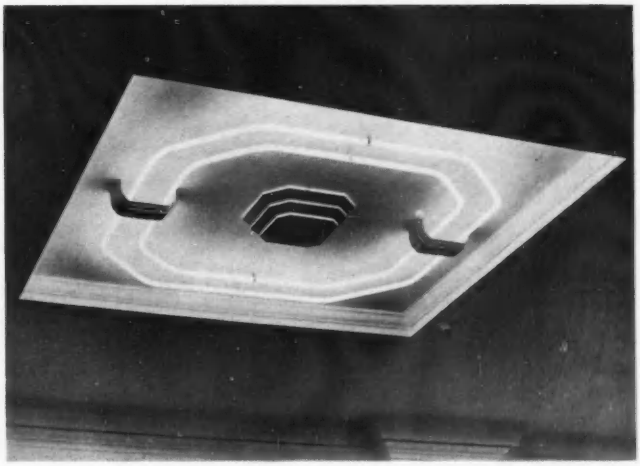

Fig. 8.—A unit comprising two 120 mA intermediate white 15-ft. lamps with electrodes and control gear concealed in the void above the false ceiling This is part of an installation at Marks & Spencer Ltd., Oxford Street, London.

Glare can be a serious fault in a lighting scheme and, although these lamps have a low surface brightness, discomfort may sometimes be caused by glare, and it may be necessary to screen the lamps. This results in a unit with a large luminous area which is usually an advantage.

When considering the possibilities of these lamps, it is important to bear in mind the maintenance problems, which may arise when lighting features are relatively inaccessible. As already stated, however, the life of Osram cold cathode fluorescent lamps may be expected to reach, or even exceed, 10,000 hours and, except for the rare occasions where a lamp may fail in the first few hundred hours due to fault conditions, it may safely be assumed that the whole installation will give trouble - free operation for the full duration of rated lamp life. After this period, or when lamps begin to fail, it will probably be more economical and cause less inconvenience to arrange for a complete lamp renewal.

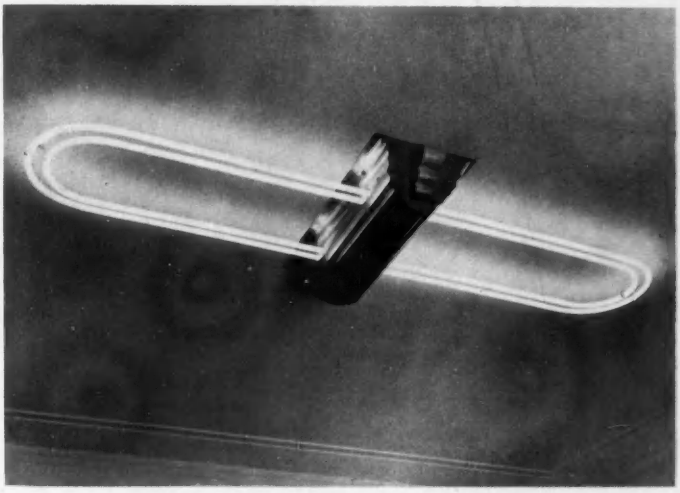

Fig. 9.—Self-contained unit with 120 mA warm white lamps and gilt metalwork.

TYPES OF DECORATIVE LIGHTING ESPECIALLY SUITED TO COLD CATHODE LAMPS

There is usually more than one way to carry out a task, but normally there is one solution that will provide the best results. In the same way there are certain types of lighting in which the use of cold cathode lamps would seem to provide the best light source from all points of view. The main features of the lamps are as under :

(*i*) High luminous efficiency.
(*ii*) Low surface brightness.
(*iii*) Large range of colours and effects.
(*iv*) Different current densities available.
(*v*) I ong trouble-free life.
(*vi*) Instant starting.
(*vii*) Ability to be dimmed.
(*viii*) Flexibility of length and shape.

The lighting features which appear to lend themselves particularly to cold cathode lamps are set out as follows :

(*a*) Visible lamp features with straight or shaped lamps, the gear being either self-contained or remote (fig. 8).
(*b*) Large lighting units which are required to give an extended area of illumination (figs. 9, 10 and 19).
(*c*) Indirect cornices, such as may surround a room or a dome or comprise circles, ellipses, rectangles or other shapes. In this connection it is interesting to note that these lamps are the only light source which can be curved or bent to the shape of any cornice and give continuous light without a break. This fact is of more than usual importance when considering the use of multiple cornices.

Typical installations of this type are shown in figs. 1, 11 and 12.

(*d*) Glazed cornices, luminous beams, or laylights, as in fig. 13. The same remarks as in (*c*) above apply to these.
(*e*) Long - line features, such as suspended trough fittings for either direct or indirect lighting.
(*f*) Louvred flush units running the length of a room or arranged as a box louvre over the entire ceiling.
(*g*) Effect lighting, such as luminous door surrounds, columns or pilasters for which the extended light source and low-surface brightness of these lamps are ideal. In such cases the lamps would be behind a glass or similar screen.

The combinations in Table 6 are used for normal straight and shaped visible lamp features. In addition they are employed in self-contained units which may also be glazed or indirect.

Pleasing effects may also be obtained by the use of, say, two outer lamps of warm white with a central one in daylight. This will give a resultant light slightly warmer than intermediate white lamps, while giving an interesting appearance to the fitting. These combinations are normally used for the more commercial type of installation, such as shops, stores and offices, as in figs. 14 and 15, where a high efficiency is required, and provided there is no particular problem with regard to the exact rendering of objects containing much red or blue.

In some situations the colours in Table 6 are not entirely suitable and a light richer in deep red rays is preferred. Examples are restaurants, places of entertainments and shops where meat and fresh food are displayed. The addition of a gold lamp to one or more of the white lamps provides a most useful combination for all applications of this kind (see Table 7).

Fig. 11.—An effective indirect lighting installation at the Clarendon Restaurant, Hammersmith, utilising a combination consisting of one line of white lamps at 120 mA and one line of gold at 60 mA.

As a guide it may be stated that two intermediate white lamps at 60 mA and one gold at 60 mA give a good general purpose light, while for restaurants and similar premises one intermediate and one gold at 60 mA are by no means too warm. In a number of cases a fitting such as the second one shown in Table 4 may provide a ready-made answer where initial cost has to be kept down.

Table 8 sets out combinations suitable for indirect cornice lighting. In general the addition of the gold lamp is to be recommended, particularly where indirect cornices are used in places of entertainment. As the room light is totally reflected from the ceiling above the cornice and if

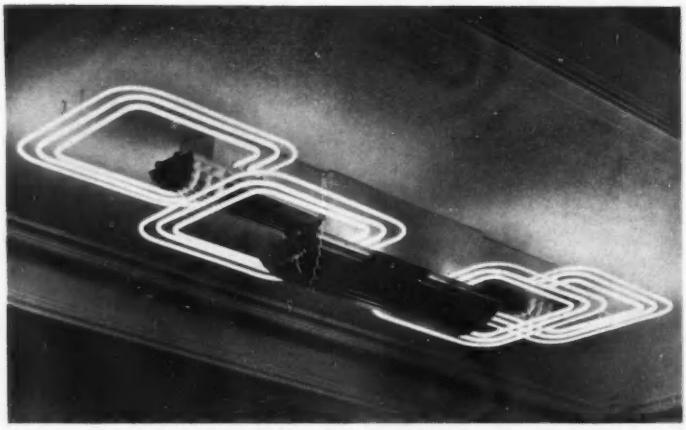

Fig. 10.—Self-contained unit with 60 mA red, dark-blue and bright-green lamps on separate circuits, the metalwork being finished gilt and cream.

TABLE 6

Colour	Number of Lines	Current in mA
1. Daylight	1, 2 or 3	60 or 120
2. Intermediate White		
3. Warm White ..		

the ceiling is normally a shade of cream, a resultant light of sufficient warmth will usually be obtained with the use of one gold lamp at 60 mA and one intermediate white lamp at 120 mA, the advantage of this arrangement being the extra light obtained from equipment costing little more than an installation in which both lamps are 60 mA. A typical cornice in which two lines of lamps are installed is shown in fig. 16.

TABLE 8

Colour	Number of Lines	Current in mA
1. Warm White ..	1 or 2	120
2. Intermediate White	1	120
2. Gold	1	60
3. Warm White ..	1	120
3. Gold	1	60

Fig. 12.—A corner of a lounge in the Royal Albion Hotel, Brighton, showing an indirect cornice containing a line of 120 mA white and a line of 60 mA gold lamps. The ceiling fittings contain the same lamp combination, the current being 60 mA for both lamps.

Table 9 sets out a combination suitable for three-colour lighting which may be used either visibly or in an indirect cornice, the latter being more effective. It depends for its full effect on blending the three colours, which is only achieved with full dimming control. This combination has been used with great success in ballrooms where the limitless colour changes obtainable provide interesting and charming effects.

It should not be thought that the above tables cover all the combinations in which these lamps can be arranged. For instance, there may be occasions when it may be advisable to use more than three lines of lamps or where a cornice may contain two gold and two white lamps according to some particular effect desired.

TABLE 7

Colour	Number of Lines (*a*)	Current in mA
1. Daylight ..	1 or 2	All 60
1. Gold	1	
2. Intermediate White	1 or 2	
2. Gold ..	1	
3. Warm White ..	1 or 2	
3. Gold	1	

NOTE.

(*a*) One or two lines of white lamps are used according to the warmth required.

TABLE 9

Colour	Number of Lines	Current in mA
Red, Deep-Blue, and Bright-Green ..	One of Each	60

THE USE OF SELF-CONTAINED UNITS OR BUILT-IN FEATURES.

Osram cold cathode lamps may be employed either in self-contained units, each of which is an entity, or in the more elaborate type of installation either built into or onto the ceiling or wall

Fig. 13.—A laylight at Hammersmith Baths illuminated from above by standard triple lamp units equipped with reflectors.

surfaces of a room. This latter might be a cornice, a large, built-in ceiling unit, a laylight, or visible lamp fitting, designed to harmonise with the architectural features of the room.

Self - contained units are to some extent controlled in size and shape by the electrical characteristics of the lamps and the range of transformers at present available, the latter dictating the size of the housing for the control gear. This can look bulky and can mar an otherwise graceful design if care is not taken. The advantage of these units is that the lighting scheme can be planned along conventional lines and the units erected by any competent electrical contractor on existing or new wiring outlets. It is worth noting that interesting arrangements can often be made, even when using a standard straight line unit, and one well-known London store has several departments where the units are mounted one to each side of a polygon, conforming to the unusual yet symmetrical shape.

On the other hand, the greatest scope is available when special features are designed to make the fullest use of the particular characteristics of the lamps as enumerated on page 95. The cost in such cases is generally higher than that of an installation of self-contained units, but the effects possible are limitless. Points to be noted in connection with either method are set out in the three succeeding paragraphs.

PRACTICAL APPLICATIONS.

In general, bare lamps should be used only in places where maximum efficiency is desired, which may include shops, stores and offices, or

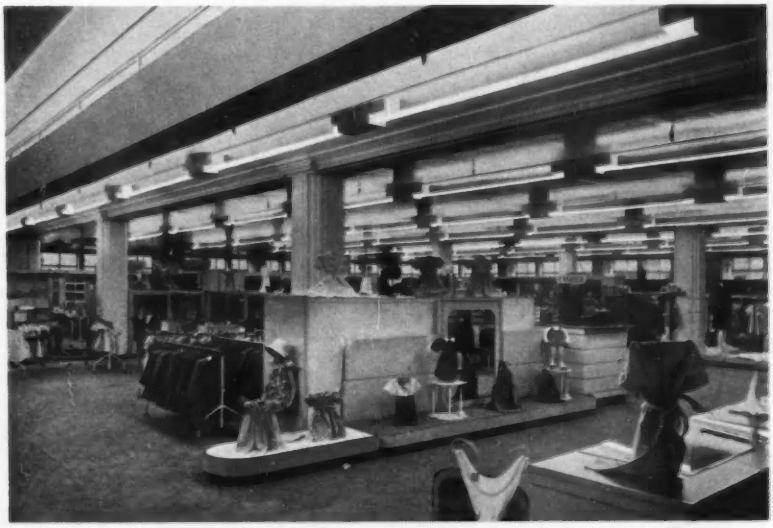

Fig. 14.—A typical floor of D. H. Evans Ltd., Oxford Street, London, showing the effective use of standard triple lamp units.

where a bright and cheerful appearance is required for a small outlay, as in cafés, dance halls and the like, but only where an adequate mounting height is available. In the better type of installation, including good-class restaurants, that there is sometimes a tendency to provide too much light in places of entertainment. While a good illumination is sometimes desired in cafés and restaurants, in other cases, as, for example, in ballrooms, a low value of illumination

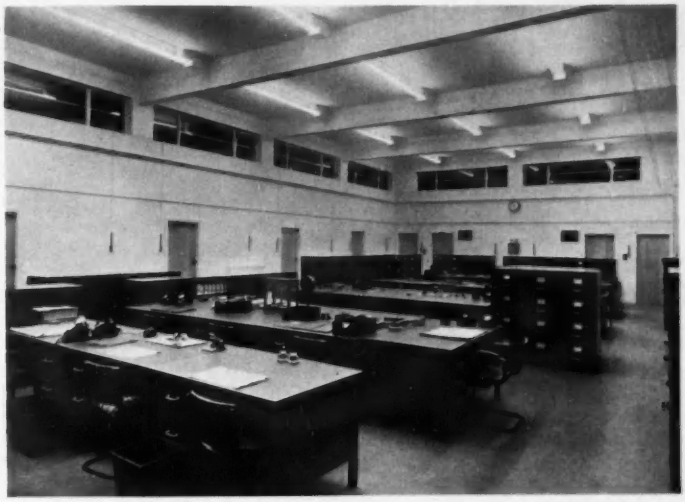

Fig. 15.—A modern office of the British-American Tobacco Co., Ltd., lighted by intermediate-white Osram fluorescent lamps of the cold cathode type. The evenness of illumination and absence of shadows at desk-level are well illustrated.

hotels and public buildings, a more dignified effect can be obtained by using the lamps behind glass or installing them in an indirect lighting cornice. At this stage it is worth mentioning

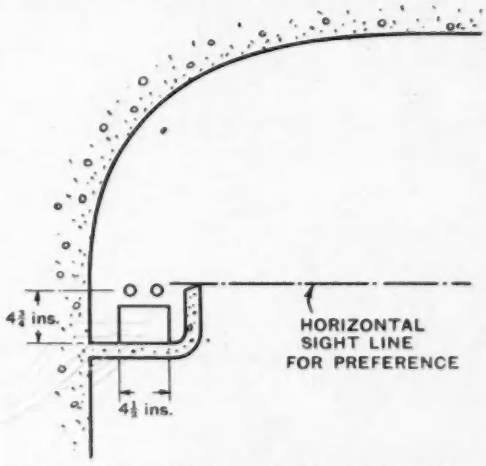

Fig. 16.—A section through a typical indirect cornice, showing the cross-sectional dimensions of a two-lamp combination.

is often sufficient, provided the light is of the correct spectral quality. This is particularly applicable to the warmer types of lighting normally employed in such places. As a matter of interest it is usually found that a cold light, such as is provided by a white fluorescent lamp, only results in a depressing and dull effect at these levels of illumination.

In places where it is decided to use bare lamps, it is always best to arrange them in double or triple lines, as a single line normally presents a very unimpressive appearance. The practice of outlining features in a room or building is usually to be condemned, since this tends to emphasise them out of all proportion to their architectural significance. Such lamps should rather be in neat simple arrangements harmonising with the main structural characteristics of the room.

Considerable contrast in surface brightness should be avoided where lamps of different colours are used side by side in visible installations. This does not apply to indirect cornice lighting when it may be more efficient to use lamps running concurrently at, say, 60 and 120 mA in order to achieve the desired effect. Here the mixing takes place out of sight and the blended colour alone is seen.

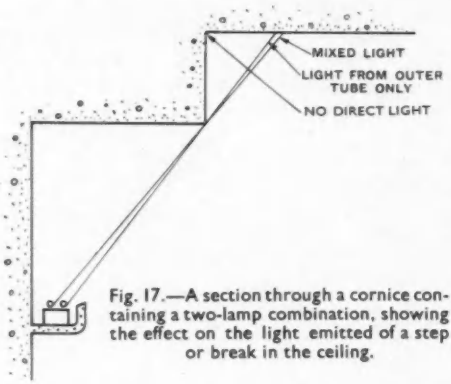

Fig. 17.—A section through a cornice containing a two-lamp combination, showing the effect on the light emitted of a step or break in the ceiling.

COLOUR AND TEXTURE OF DECORATIONS.

In the past with tungsten light sources, some distortion of the colour of room decorations and furnishings has become acceptable through long usage. The white fluorescent light source with its different spectral composition has created a problem in this respect because certain colours are distorted in an unfamiliar way. Blues generally tend to appear purplish, especially under the warmer white lamps, this being particularly so with strong blues such as ultra-marine and royal blue. Yellows such as chrome, or mixed pastel colours such as a cream containing a fair quantity of chrome tend to become somewhat vivid and harsh. Pink colours which have a fair blue content, tend to be over-accentuated under mercury fluorescent light, therefore one may say that such colours should, if possible, be avoided for decoration where a white fluorescent light source only is in use. Creams should be derived from an ochre base rather than chrome, while pinks should tend more towards salmon, being derived from white, a yellow red and a trace of grey. The deeper creams, tending towards a pale coffee colour have also been found successful—these should consist of white, ochre and a touch of burnt sienna. It is wise to avoid a decorative scheme where blue predominates as this tends to appear somewhat depressing under any sort of lighting. Discretion should also be exercised where green decorations are contemplated, as the same remarks are largely applicable.

With combinations of mercury and neon fluorescent lamps it becomes possible to render blue colours satisfactorily, even when the result-

TABLE 10.
DATA FOR THREE TYPICAL DECORATIVE SELF-CONTAINED UNITS.

REFERENCE No.	FY. 7053 (fig. 9)	FY. 7064 (fig. 7)	FY. 7074 (fig. 10)
Overall length of unit	7 ft. 5 ins.	6 ft. 11 ins.	10 ft. 11 ins.
Number and colour of lamps	2 White (*a*)	3 White (*a*) or 2 White (*a*) 1 Gold	4 Red 4 Dark-Blue 4 Bright-Green
Lamp current	120 mA	60 mA	60 mA
Overall visible length of lamps to each colour ..	28 ft.	White : 39 ft., or White : 26 ft. Gold : 13 ft.	Red : 40 ft. Blue : 34 ft. Green : 28 ft.
Average light output of unit over 10,000 hours	7,000 lumens	All White : 4,875 lumens. White and Gold : 4,910 lumens.	11,260 lumens
Overall consumption of unit	250 watts	White : 170 watts White and Gold : 210 watts	610 watts
Power Factor	0·85	0·85	0·85
Life of lamps	10,000 hrs.	10,000 hrs.	10,000 hrs.
Approximate weight of complete fitting ..	50 lbs.	60 lbs.	200 lbs.

NOTE.

(*a*) Normally daylight, intermediate white or warm white.

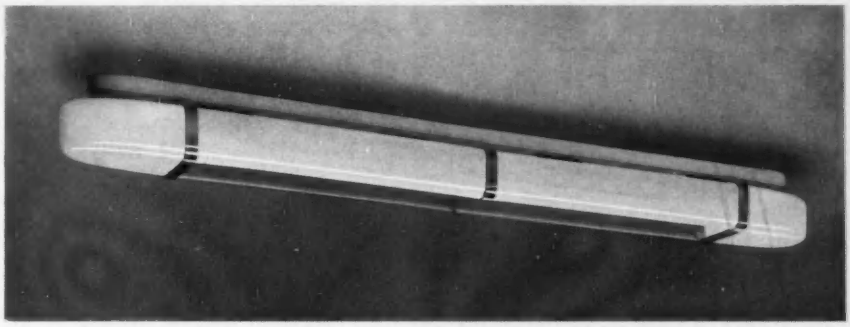

Fig. 18.—Self-contained unit with three 8-ft. 6-ins. lamps with turned back electrodes, available in the combinations shown in Table 4, columns 2, 3 and 5. The end pieces are white opal "Perspex" and the side panels are clear reeded "Perspex". The bottom of the unit is open for direct downward lighting.

ant light is quite warm. Also the red end of the spectrum is properly rendered without overstressing the green and yellow region.

Considerably more latitude may therefore be used in the choice of decorations where a gold fluorescent lamp is added and excellent results are obtained with equal lengths of intermediate white and gold lamps, both running at 60 mA. While considering the decorations, it is worth bearing in mind that surface irregularities in walls and ceilings are shown up by specular reflection. For this reason it is preferable to use matt finish paints on a plain surface, though they may be applied on a spattered surface, if an interesting texture is required, and this combination is specially successful in concealing such irregularities.

INSTALLATION POINTS.

Self-contained units offer the simplest method of using cold cathode lamps, since they are delivered wired and can generally be connected to an existing wiring outlet. It should, however, be borne in mind that as these fittings tend to be heavy for their size, owing to the weight of the control gear, secure fixings should be arranged.

Fig. 19.—Part of a foundry at C. A. Parsons & Co., Ltd. heavy engineering works with triple lamp cold cathode units at 40 feet mounting height.

Data regarding figs. 7, 9 and 10 is given in Table 10.

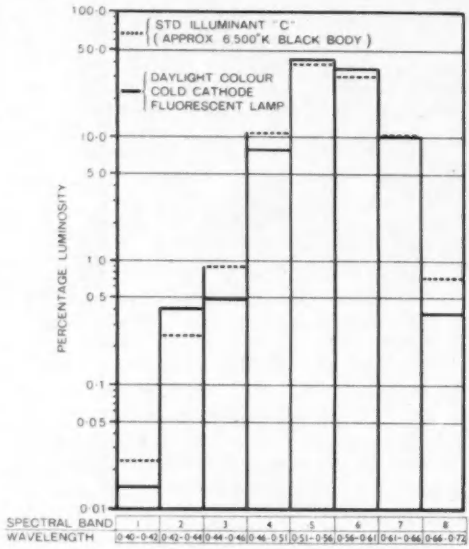

Fig. 20.—Luminosity distribution of special cold cathode fluorescent lamps used in colour-matching unit.

When the lamps are used in cornices, line features or built-in features, it is often necessary to place the gear remote from the lamps. The positions available for the remote mounting of gear should be chosen with some care and should be accessible for maintenance, well ventilated, dry and temperate. Where the available space is small the transformers only need be accommodated, the capacitors being mounted elsewhere. Transformers should wherever possible be installed within 10 feet of their respective lamps unless exceptional circumstances dictate otherwise. This is because long lengths of metal-shielded cable may introduce unwanted capacity into the high-voltage circuit, giving rise to high resonant voltages as explained elsewhere.[3]

Where two or more colours are used in a cornice, care should be taken to arrange the lamps so that one does not cast a shadow of the other; the stronger colour should normally be farthest from the reflecting wall surface. If there is a step in the ceiling a slight coloured shadow may be noticed, due to part of the ceiling receiving light from the outer lamp only (fig. 17).

The preceding remarks apply to some extent when a two-colour combination is used horizontally near a wall. A coloured band may be observed on the wall where light is received from the nearer lamp only, owing to the farther one, in effect, throwing a shadow of the outer one on the wall.

COLD CATHODE FLUORESCENT LAMPS IN INDUSTRY.

No attempt will be made here to describe in detail the many varied types of installation in industry where cold cathode lamps can be effectively used. The reasons for selecting this type of lamp may differ from one installation to another, but an important consideration which appeals to maintenance engineers in particular is their unusually long life in comparison with other light sources. When installed in an average workshop or factory the life of 10,000 hours will spread over a number of years, during which it should not be necessary to replace lamps except when failure arises due to exceptional causes. The periodic cleaning of lamps and fittings can be arranged to be carried out at specific times with a minimum of inconvenience, and apart from this no further attention should be required until the end of the useful life, when complete re-lamping should be considered.

The general lighting in industrial undertakings often involves fittings being fixed in positions which are relatively inaccessible, and considerable time and expense may be involved if frequent lamp replacements are necessary. An example of a cold cathode lamp installation in which triple lamp units fitted with enamelled dispersive reflectors are used is shown in fig. 19. This is part of an installation of 500 similar fittings, many of which are at a mounting height

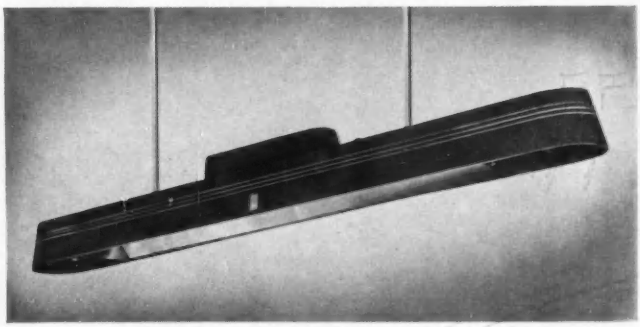

Fig. 21.—Cold cathode colour-matching unit.

of 40 ft., and provide an average service illumination of 12/15 L/sq. ft. The extended light sources are useful where large areas have to be lighted with a reasonably even illumination ; when the lighting layout is correctly planned unwanted shadows are practically eliminated.

When a reasonably high-mounting height is possible the lamps can often be used unscreened, without glare. The surface brightness of the different lamps is given in Table 1.

COLOUR-MATCHING UNITS.

In many industries where the accurate production of articles is dependent on their being matched for colour against standards, the periods of working are restricted to hours when suitable natural daylight is available. Such work as the manufacture of paints, enamels and printer's inks, also the dyeing of fabrics and textiles and the accurate matching of furs, are but a few of the industries which rely upon the provision of natural daylight.

A colour-matching unit recently introduced by the G.E.C., provides a satisfactory substitute for natural daylight for such applications. This incorporates special fluorescent lamps of the cold cathode type which provide a quality of light very close to that from an average overcast north sky ; the spectral composition of the light compared with an international standard for artificial daylight is shown in fig. 20. Lamps of the cold cathode type have been selected for this application because of their good lumen maintenance and therefore constancy of colour rendering throughout life. The unit shown in fig. 21 is fitted with mirror reflectors designed to give an average illumination of 50 L/sq. ft. over an area of 4 ft. by 2 ft. at a mounting height of 3 ft.

The transformer is accommodated in the housing above the reflector and, as the unit is normally used within easy reach of the operatives, interlocks are incorporated in all accessible covers to the high-voltage circuit. These automatically disconnect the supply to the transformer when any cover is opened. The overall consumption is 90 watts.

SAFETY PRECAUTIONS.

Although high voltages are associated with the operation of cold cathode lamps, the danger is by no means increased if the proper precautions are taken.

British Standard No. 559 clearly defines the precautions to be taken when designing the lighting units and transformers, while the installation should be carried out in accordance with the requirements of I.E.E. Regulations.

It is desirable to make provision for the efficient isolation of high-voltage circuits to protect those who may have to work on or near the equipment for maintenance purposes. A method which ensures adequate protection is the inclusion of a switch or fuseboard in the circuit containing the transformers, which can be locked when the supply has been disconnected on both poles and is under the control of authorised persons only.

An alternative method of protection with units of the self-contained type may be obtained by the incorporation of an interlock in the unit which automatically disconnects both poles of the supply when any access cover of the high-voltage gear is removed. A further alternative method for self-contained units would be the provision of a plug and socket either on the unit or immediately adjacent, which isolates both poles of the supply when the plug is withdrawn.

The electrodes are usually protected by metal electrode boxes and these are designed to ensure that the clearances specified in the above-mentioned specification are provided.

CONCLUSION.

The best results in any lighting installation are only obtained where skilful use is made of the most suitable illuminant for the scheme under consideration. This article has been confined to a description of some of the varied applications in which Osram cold cathode lamps have been successfully used.

The special characteristics of long life, wide range of colours and effects, and general flexibility have already firmly established the cold cathode lamp as an effective lighting source.

Within the last few years long hot cathode lamps have become available in the U.S.A., and similar lamps may possibly be marketed in this country. Because of their somewhat higher efficiency, such lamps are likely to find applications where luminous efficiency, rather than long life and flexibility in use, is the dominating consideration.

REFERENCES.

1. H. G. JENKINS and J. N. BOWTELL, *I.E.S. Trans.*, 1948.
2. British Patent, application No. 13954 46.
3. H. G. JENKINS and C. DYKES BROWN, *G.E.C. Journal*, Vol. IX, No. 3, August, 1938, p. 169.

Hematite Milling Plant at Marampa, Sierra Leone

AN INSTALLATION FOR THE SIERRA LEONE DEVELOPMENT COMPANY LIMITED.

By G. L. L. STONE, A.R.S.M., D.I.C., M.I.M.M.
Fraser & Chalmers Engineering Works.

Fig. 1.—New mill showing thickeners in front and to the right ; no. 6 conveyor in the foreground. Part of the old mill is seen on the left.

INTRODUCTORY.

THE new concentrating plant at Marampa belonging to the Sierra Leone Development Company was manufactured, erected, and put into operation by Fraser & Chalmers Engineering Works early in 1944. The plant was ordered in 1941 and the scheme was carried out as a direct contribution to the British war effort by providing urgently needed supplies of iron ore.

The mill was built in order to replace the old concentrator which treated the pulverulent specular hematite ore until the time of the change-over to the new mill. Its purpose was to double the output of iron ore concentrates, without increasing the total daily consumption of water. While achieving this main objective, it was also desired to improve recovery of the iron and the grade of the concentrates.

George T. Holloway & Company were the

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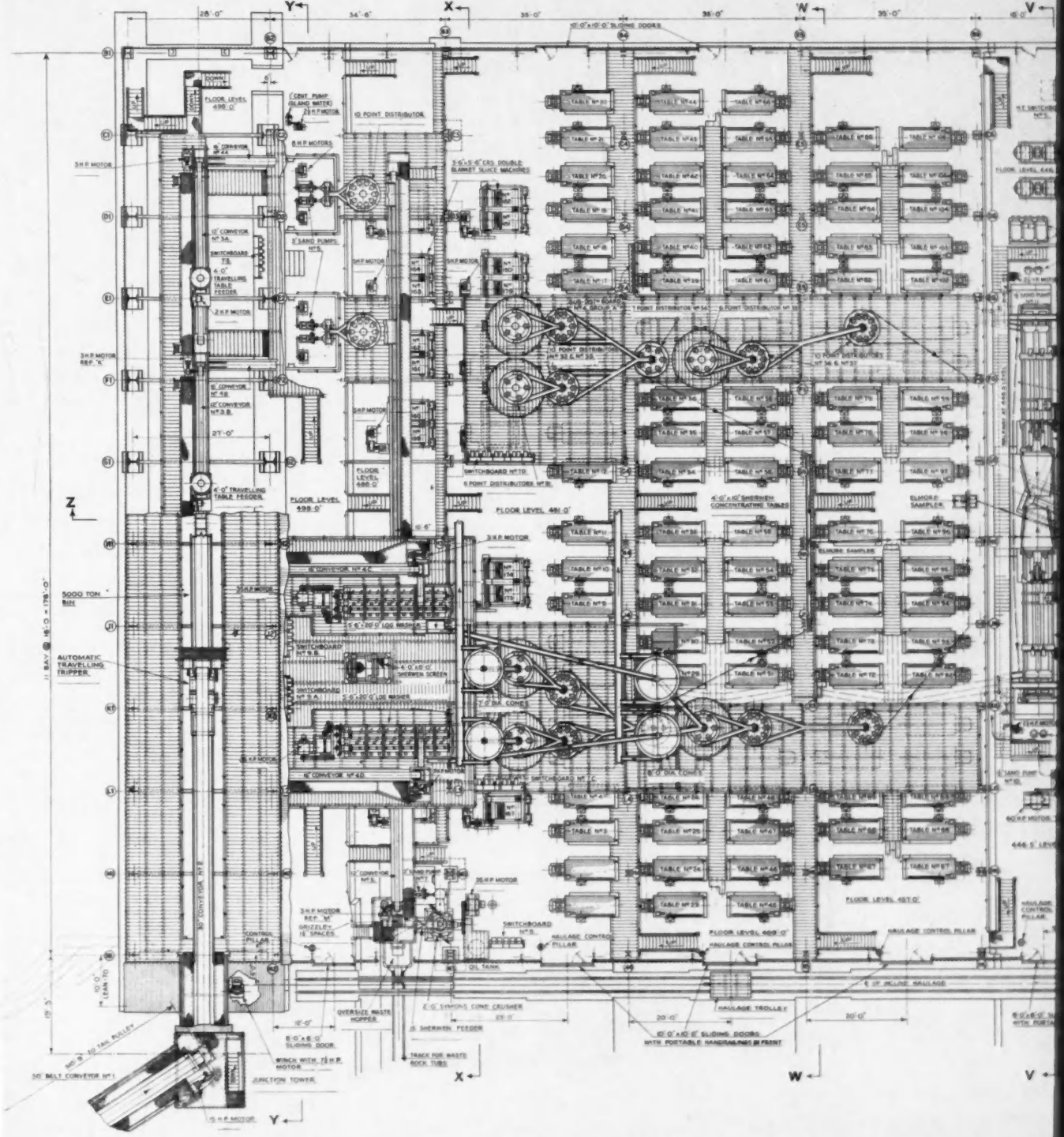

AUTOMATIC TRAVELLING TRIPPER
5000 TON BIN
FLOOR LEVEL 490'-0"
FLOOR LEVEL 498'-0"
FLOOR LEVEL 481'-0"
FLOOR LEVEL 469'-0"
FLOOR LEVEL 457'-0"
10 POINT DISTRIBUTOR
6 POINT DISTRIBUTORS
SWITCHBOARD
4'-0" TRAVELLING TABLE FEEDER
4'-0"x10" SHERWEN CONCENTRATING TABLES
ELMORE SAMPLER
SHERWEN SCREEN
7'-0" DIA. CONES
HAULAGE CONTROL PILLAR
HAULAGE TROLLEY
OVERSIZE WASTE HOPPER
JUNCTION TOWER
OIL TANK
50' BELT CONVEYOR No. 1
TRACK FOR WASTE ROCK TUBS

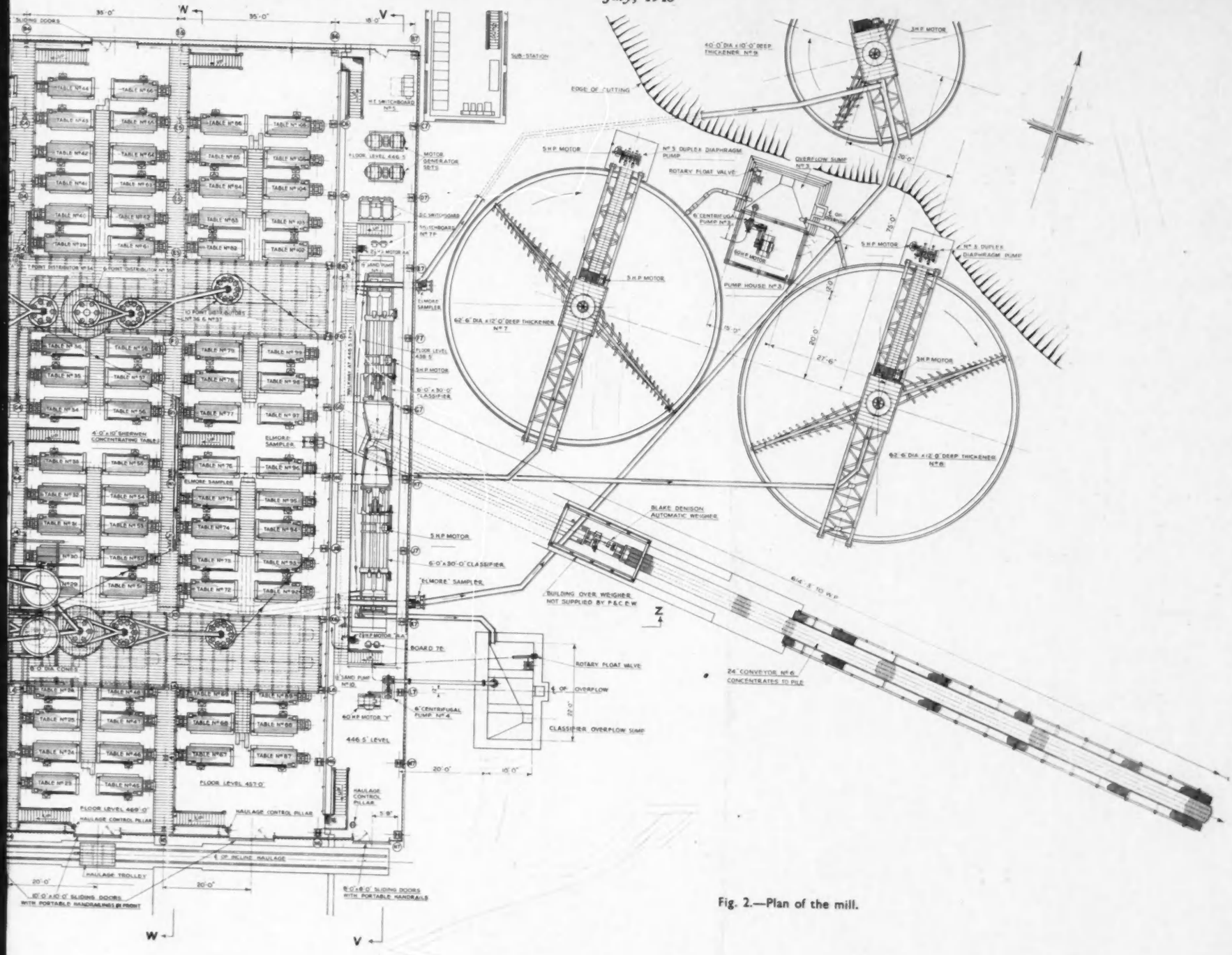
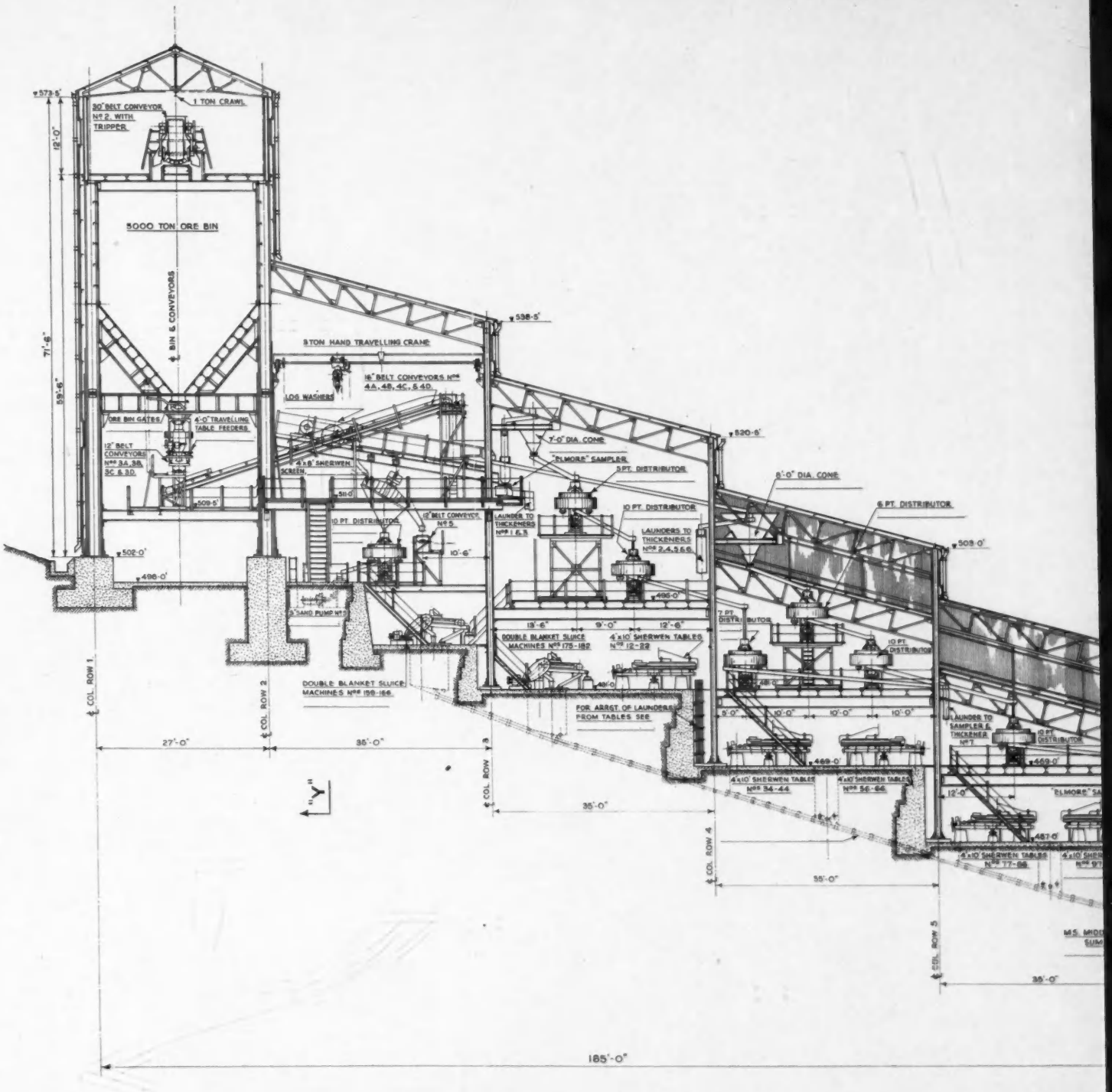

SUB-STATION
MOTOR GENERATOR SETS
5 H.P. MOTOR
No. 3 DUPLEX DIAPHRAGM PUMP
ROTARY FLOAT VALVE
OVERFLOW SUMP No. 3
6" CENTRIFUGAL PUMP No. 3
PUMP HOUSE No. 3
62'-6" DIA. x 12'-0" DEEP THICKENER No. 7
40'-0" DIA. x 10'-0" DEEP THICKENER No. 9
62'-6" DIA. x 12'-0" DEEP THICKENER No. 8
BLAKE DENISON AUTOMATIC WEIGHER
BUILDING OVER WEIGHER NOT SUPPLIED BY P&CEW
24" CONVEYOR No. 6 CONCENTRATES TO PILE
6" CENTRIFUGAL PUMP No. 4
CLASSIFIER OVERFLOW SUMP
446.5' LEVEL
FLOOR LEVEL 437'-0"
FLOOR LEVEL 449'-0"
HAULAGE CONTROL PILLAR
4° INCLINE HAULAGE
HAULAGE TROLLEY
4'-0" x 10' SHERWEN CONCENTRATING TABLES
ELMORE SAMPLER
6'-0" DIA. CONES
6'-0" x 30'-0" CLASSIFIER
10 POINT DISTRIBUTORS
7 POINT DISTRIBUTOR
6 POINT DISTRIBUTOR
SLIDING DOORS

Fig. 2.—Plan of the mill.


30" BELT CONVEYOR No 2. WITH TRIPPER
1 TON CRAWL
5000 TON ORE BIN
BIN & CONVEYORS
9 TON HAND TRAVELLING CRANE
16" BELT CONVEYORS Nos 4A, 4B, 4C, & 4D
LOG WASHERS
ORE BIN GATES
4'-0" TRAVELLING TABLE FEEDERS
12" BELT CONVEYORS Nos 3A, 3B, 3C & 3D
4'x8' SHERWEN SCREEN
7'-0" DIA. CONE
"ELMORE" SAMPLER
5 PT. DISTRIBUTOR
8'-0" DIA. CONE
6 PT. DISTRIBUTOR
10 PT. DISTRIBUTOR
18" BELT CONVEYOR No 5
LAUNDER TO THICKENERS Nos 1 & 3
LAUNDERS TO THICKENERS Nos 2,4,5 & 6
7 PT. DISTRIBUTOR
10 PT. DISTRIBUTOR
3" SAND PUMP No 7
DOUBLE BLANKET SLUICE MACHINES Nos 175-182
4'x10' SHERWEN TABLES Nos 12-22
DOUBLE BLANKET SLUICE MACHINES Nos 150-166
FOR ARRGT. OF LAUNDERS FROM TABLES SEE
LAUNDER TO SAMPLER & THICKENER No 7
10 PT. DISTRIBUTOR
4'x10' SHERWEN TABLES Nos 34-44
4'x10' SHERWEN TABLES Nos 50-66
4'x10' SHERWEN TABLES Nos 77-88
"ELMORE" SA
M.S. MOD SUM
COL. ROW 1
COL. ROW 2
COL. ROW 3
COL. ROW 4
COL. ROW 5
27'-0"
35'-0"
35'-0"
55'-0"
35'-0"
185'-0"
538-5'
520-6'
509-0'
509-5'
502-0'
498-0'
496-0'
469-0'
487-0'
71'-6"
59'-6"
12'-0"
10'-6"
19'-6"
9'-0"
12'-6"
5'-0"
10'-0"
10'-0"
10'-0"
12'-0"

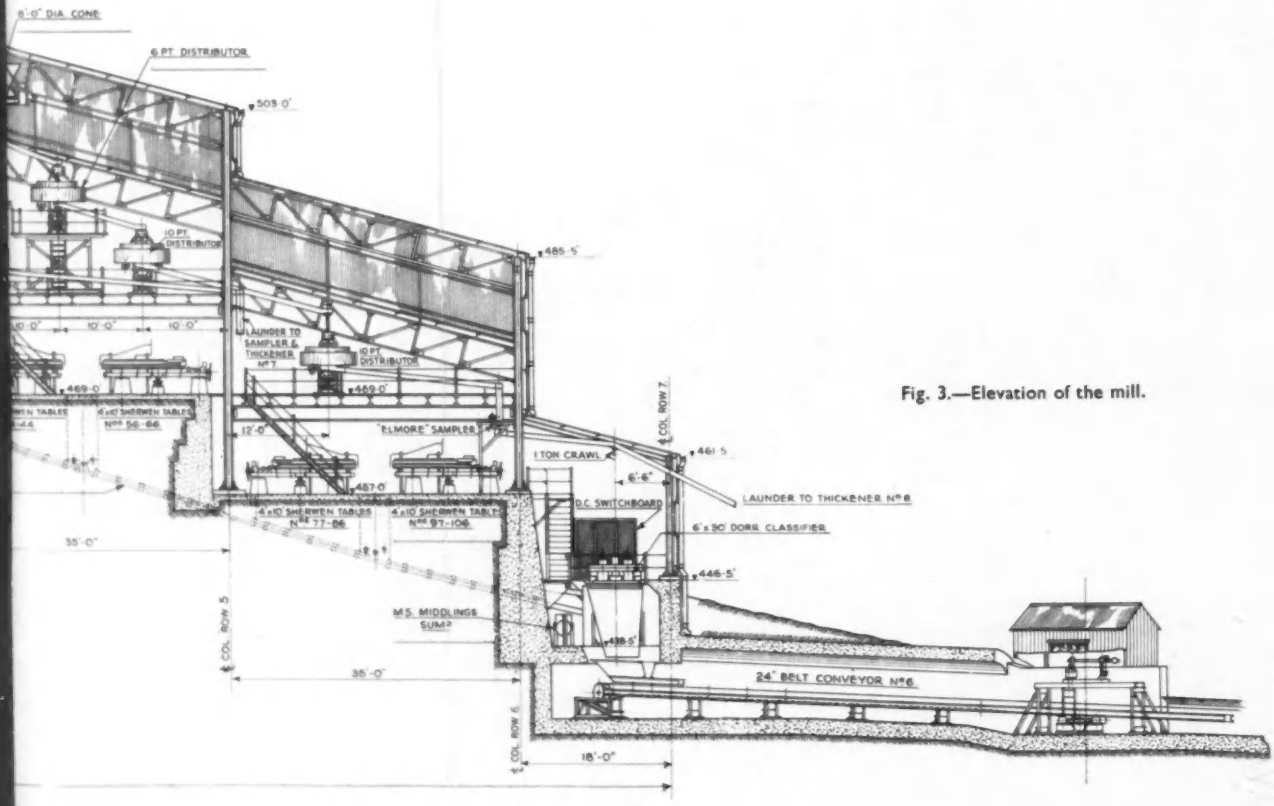
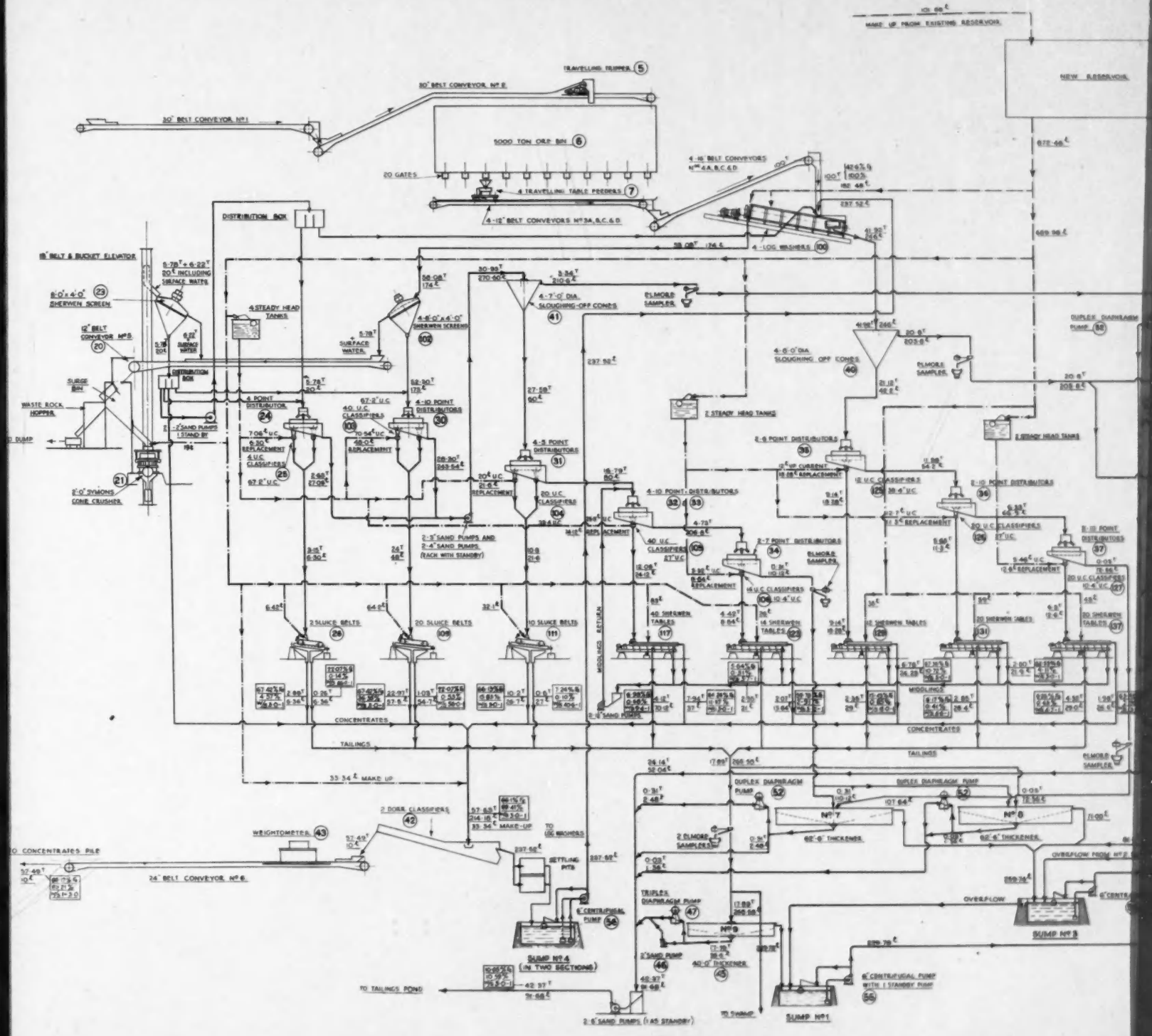


Fig. 3.—Elevation of the mill.


MAKE UP FROM EXISTING RESERVOIR
NEW RESERVOIR
TRAVELLING TRIPPER (5)
30" BELT CONVEYOR, Nº 2
30" BELT CONVEYOR Nº 1
5000 TON ORE BIN (6)
20 GATES
4 TRAVELLING TABLE FEEDERS (7)
4-15" BELT CONVEYORS Nos 4A, B, C & D
4-12" BELT CONVEYORS Nº 3A, B, C & D
4 - LOG WASHERS (100)
DISTRIBUTION BOX
18" BELT & BUCKET ELEVATOR
8'-0" x 4'-0" SHERWEN SCREEN (23)
12" BELT CONVEYOR Nº 5 (20)
SURGE BIN
WASTE ROCK HOPPER
2'-0" SYMONS CONE CRUSHER (21)
4 STEADY HEAD TANKS
4 POINT DISTRIBUTOR (24)
4-10 POINT DISTRIBUTORS (30)
4-5 POINT DISTRIBUTORS (31)
4-6'-0" x 4'-0" SHERWEN SCREENS (102)
4-7'-0" DIA SLOUGHING-OFF CONES (41)
4-6'-0" DIA SLOUGHING OFF CONES (40)
ELMORE SAMPLERS
2 STEADY HEAD TANKS
2-6 POINT DISTRIBUTORS (38)
4-10 POINT DISTRIBUTORS (32) (39)
2-7 POINT DISTRIBUTORS (34)
2-10 POINT DISTRIBUTORS (36)
DUPLEX DIAPHRAGM PUMP (52)
2-5" SAND PUMPS AND 2-4" SAND PUMPS (RACK WITH STANDBY)
2-5" SAND PUMPS (1 AS STANDBY)
2 SLUICE BELTS (26)
20 SLUICE BELTS (109)
10 SLUICE BELTS (111)
40 SHERWEN TABLES (117)
14 SHERWEN TABLES (123)
32 SHERWEN TABLES (128)
20 SHERWEN TABLES (131)
MIDDLINGS RETURN
MIDDLINGS
CONCENTRATES
TAILINGS
33.34 MAKE UP
2 DORR CLASSIFIERS (42)
WEIGHTOMETER (43)
TO CONCENTRATES PILE
24" BELT CONVEYOR Nº 6
SETTLING PITS
6" CENTRIFUGAL PUMP (54)
SUMP Nº 4 (IN TWO SECTIONS)
TRIPLEX DIAPHRAGM PUMP (47)
2" SAND PUMP (46)
40'-0" THICKENER (45)
Nº 9
Nº 7
Nº 8
62'-6" THICKENER
OVERFLOW FROM Nº 2
OVERFLOW
SUMP Nº 3
6" CENTRIFUGAL PUMP WITH 1 STANDBY PUMP (55)
SUMP Nº 1
TO TAILINGS POND
TO SWAMP

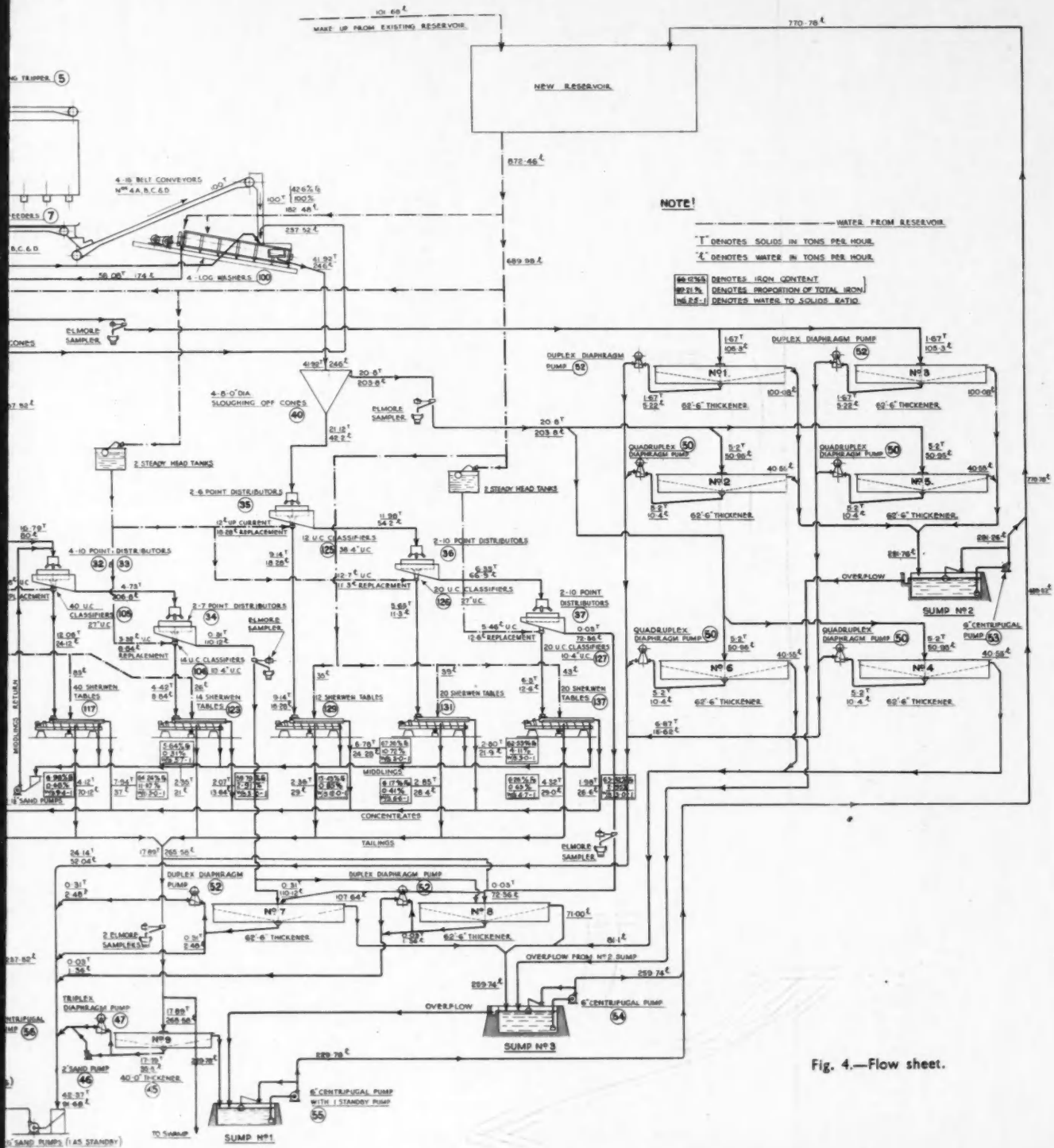


Fig. 4.—Flow sheet.

consulting metallurgists and they also carried out the test work. The plant was designed in collaboration with the Consultants.

The mill is situated at the mine, which is a few miles from the village of Marampa in the Port Lokko District of the Sierra Leone Protectorate.

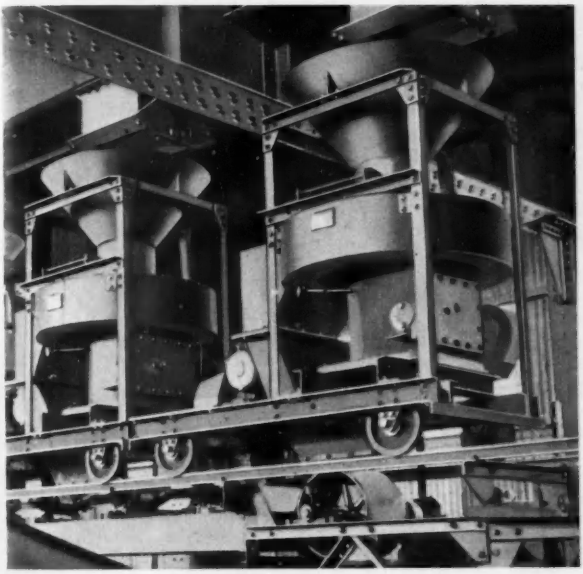


Fig. 5.—The 4-ft. diameter travelling feed tables under the bin.

A good motor road connects it with Freetown which is some 85 miles distant. The Company's railway runs to Pepel, the shipping port, which is 52 miles away at the mouth of the River Rokel.

The mineral deposit consists of an upper layer of hard hematite ore of varying thickness. Below this layer is the high-grade pulverulent specular hematite which the mill was designed to treat. The wall rock of the ore body is a muscovite schist. The gangue to be separated from the ore consists of about 40 per cent flaky mica and 10 per cent granular quartz. Phosphorus is not found in the quartz or the micaceous iron, but it is carried in the ore slime up to 0·19 per cent. The mica has a limonitic coating in parts and this latter carries up to 0·16 per cent phosphorus.

The ore is designated powder ore, and this name describes its character. After treatment in the log washer only a small quantity has to be reduced by crushing. Eighty to ninety per cent is minus one-eighth of an inch in size, and is ready for gravity concentration.

ORE TREATMENT.

From a concrete hopper 52 ft. long by 8 ft. 6 ins. wide situated above the mill, the powder ore is brought downhill to the mill conveyor no. 1 by a series of three conveyors. These conveyors are all 30 ins. wide, run at 250 ft. per minute and have a capacity of 300 tons of iron ore per hour. Their lengths are 604 ft., 372 ft., and 262 ft., and they are fitted with 25-, 20- and 15-h.p. motors respectively.

A grizzly is mounted on top of the hopper and consists of longitudinal bulb tees spaced at 4 inches. The upper tables of the tees are protected by renewable steel wearing strips. The supporting joists are 12 ins. by 5 ins.

The ore is brought over the grizzly by a scraper. At the bottom of the hopper there are 4 Sherwen vibrating feeders, each taking 3½ h.p., which feed the ore on to the first conveyor of the system.

The motors for the first two conveyors act as induction generators when the conveyors are fully loaded and driving the motors. The current so generated is passed back to the line.

Fig. 1 gives an impression of the general aspect of the Mill. Figs. 2 and 3 show the plan and elevation, and these together with the flow sheet, fig. 4, illustrate the layout and the metallurgical treatment.

The Robins conveyor no. 1 feeds on to the conveyor no. 2, which is situated above the ore bin. A Blake-Denison weigher is installed on the no. 1 conveyor. Conveyor no. 2 has a Robins automatic tripper which distributes the ore equally. The bin has a capacity of 5,000 tons of iron ore and is provided with 20 bottom discharge chutes fitted with double radial gates.

After the bin, the mill is divided into four sections each capable of treating 25 tons per hour of mill-feed, making the total capacity of the plant 100 tons per hour.

From the gates four 4-ft. travelling table feeders, no. 7, illustrated in fig. 5, regulate the ore on to four 12-inch conveyors no. 3, which in turn feed on to four 16-inch conveyors no. 4. These conveyors deliver the ore to four 5 ft. 6 ins. by 20 ft. log washers, no. 100; one of these machines is illustrated in fig. 6.

The oversize from the log washers goes to four 8-ft. by 4-ft. Sherwen vibrating screens, no. 102, fitted with ½-inch opening screencloths. The plus ½-inch material, which is from 10 per cent

to 20 per cent of the total feed, is crushed and is returned for re-treatment.

The minus ⅛-inch product, approximately 54 per cent plus 60 mesh, is classified in upward current classifiers, fig. 7, into four fractions. After the first classification the slimes are removed in four 7-ft. dia. cones, no. 41. The classifications are as follows :—classifiers no. 103, upward current 67·2 inches per minute ; classifiers no. 104, upward current 38·4 inches per minute ; classifiers no. 105, upward current 27 inches per minute and classifiers no. 106, upward current 10·4 inches per minute.

The spigot discharges from the classifiers no. 103 and no. 104 go to sluice belts. The ore to these machines consists of flat particles of the micaceous hematite, rounded particles of quartz and a little rounded red hematite ore. The former are not washed down the belt by the sprays, but cling to the belt and are discharged at the head of the machine as concentrates. The granular quartz and the low-grade red hematite ore are washed down to the tailings launder.

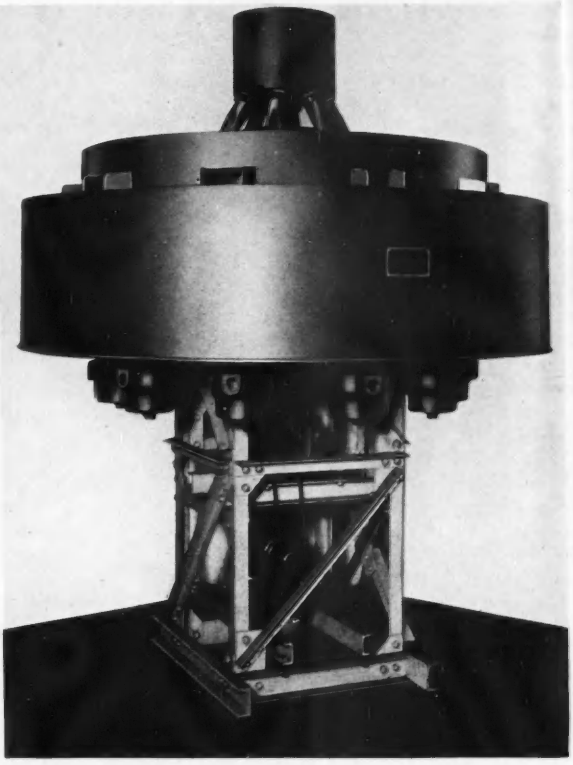


Fig. 7.—10 spigot upward current classifier and distributor.

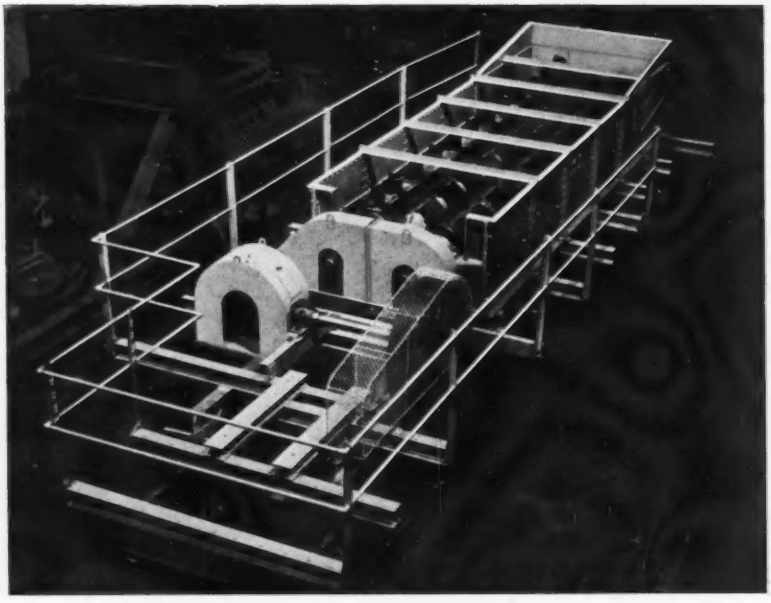


Fig. 6.—Log washer, 5 ft. 6 ins. wide by 20 ft. long.

Fig. 10 shows one of the sluice machines. The consultants found from their experiments that a belt machine very efficiently separated the quartz from the hematite at the larger sizes. In consequence, Fraser & Chalmers in collaboration with George T. Holloway & Company, designed the machine which has been proved to be most satisfactory in operation.

The machine has two endless rubber belts, each 3-ft. 6-ins. effective width by 5-ft. 6-ins. pulley centres, arranged in a mild-steel framework and operated by chain drive from a worm reducing gearing directly coupled to a P.I.V. gearbox which is driven from a 5-h.p. motor by a Vee rope. The slope of the belt may be adjusted as required by a handwheel, and the speed of the belt can be varied from 20 ft. per minute to 40 ft. per minute. There are 16 of these double sluice machines in the mill.

The spigot discharges of the classifiers no. 105 and no. 106 are treated on 10-ft. by 4-ft. Sherwen tables ; fig. 8 shows a bank of tables in the course of installation. There are, in all, 106 of these tables in the mill.

The feed to the tables from the classifiers no. 105 and no. 106 is quite different from that from the classifiers no. 103 and no. 104, the gangue consisting chiefly of flaky mica and very little quartz.

The overflows from the log washers, about 15 per cent plus 60 mesh B.S.S. size, after being deslimed in four 8-ft. diameter cones, no. 40, are classified into three fractions as follows : classifier no. 125, upward current 38·4 inches per minute, classifiers no. 126, upward current 27 inches per minute, and classifiers no. 127, upward current 10·4 inches per minute. These spigot discharges are treated on Sherwen tables, the feed consisting chiefly of flaky mica and the finer hematite.

The Sherwen tables make the products : concentrates, middlings and tailings. The middlings do not consist of included particles, that is, the gangue and hematite are separate, and therefore this product is pumped back for retreatment.

The overflows from the 7-ft. and 8-ft. cones, classifiers no. 106 and no. 127, and the tailings from the sluice belts and tables, gravitate to their respective Dorr thickeners as shown on the flow sheet fig. 4. The thickened pulp is pumped to the tailings dam, and the clear water overflow is pumped from three pumping stations to the mill reservoir. Each station is equipped with two 6-in. Gwynnes centrifugal pumps, one of which is a standby.

The tailings pump house is equipped with two 5-in. M type sand pumps driven by 22-h.p. motors. One of the pumps is a standby. Each pump has the approximate capacity of 525 gallons per minute.

The concentrates from the sluice belts and tables flow to the two 6-ft. wide by 30-ft. long

Fig. 8.—Sherwen 10 ft. by 4 ft. concentrating tables in course of erection.

BRITISH STANDARD SIEVE SCALE	LOG WASHER COARSE		LOG WASHER OVERFLOW		SHERVEN SCREEN UNDERSIZE		103 SPIGOT		103 OVERFLOW		7'-0" CONE OVERFLOW		7'-0" CONE SPIGOT		104 SPIGOT		104 OVERFLOW		105 SPIGOT		105 OVERFLOW		106 SPIGOT		106 OVERFLOW		8'-0" CONE SPIGOT		8'-0" CONE OVERFLOW		125 SPIGOT		125 OVERFLOW		126 SPIGOT		126 OVERFLOW		127 SPIGOT		127 OVERFLOW		TABLE & SLUICE BELT TAILINGS		CONCENTRATES		DORR CLASSIFIER OVERFLOW	
	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe	Wt	Fe
+7	10·1	63·2			0·5	60·9	0·5	60·6																					0·3												0·6	52·1	0·8	65·9		
−7+18	4·7	55·3	0·2	—	3·7	54·6	3·6	53·7	0·1	—			0·1	—													0·7	19·4			2·6	24·9	0·1	—	0·3	—	0·1	—	0·1	—			5·9	38·4	2·2	63·8		
−18+44	19·0	54·5	5·2	21·2	26·1	57·2	32·4	59·1	8·2	25·4			8·6	30·4			5·3	8·1	5·8	7·1	1·1	8·3	2·3	20·7	0·7	5·9	10·2	39·9			26·7	50·5	7·2	16·4	13·7	19·9	3·8	8·7	6·0	9·9	1·0		23·7	17·6	20·7	63·6	0·4	—
−44+60	20·4	56·5	9·8	24·3	17·2	59·4	24·0	64·6	16·1	36·6	1·1	—	11·9	38·0			10·6	13·0	12·5	12·8	8·8	8·7	8·8	7·7	5·1	7·5	50·2	38·8	0·2	—	21·1	64·5	12·7	20·0	18·8	34·7	12·3	11·4	20·0	15·7	4·9		23·7	18·2	28·0	67·1	1·9	19·3
−60+120	36·9	57·9	36·0	35·2	36·8	62·5	31·9	66·5	46·7	50·6	15·6	9·5	46·7	51·2			41·4	31·9	43·5	32·6	28·7	12·6	47·6	16·6	24·6	14·7	19·2	50·0	9·6	7·9	40·1	67·5	42·6	34·5	47·8	57·5	38·9	22·0	38·2	30·0	34·5		37·7	22·3	34·9	67·5	22·4	36·1
−120+200	8·9	58·7	18·9	45·1	8·6	60·6	7·6	62·8	28·9	43·1	13·5	14·7	21·2	61·6			22·8	53·4	23·8	59·8	26·0	33·7	41·3	50·9	69·6	34·6	19·7	52·4	13·7	11·7	7·1	67·3	19·5	50·1	14·7	67·6	20·1	42·6	18·3	56·8	59·6		8·4	35·6	13·4	68·5	30·1	60·6
−200			29·9	26·3	7·1	37·8					69·8	20·1	11·5	58·7			19·9	55·4	14·4	65·1	35·4	43·0							76·5	21·2	2·1	58·6	17·9	45·0	4·7	60·5	24·8	42·6	17·4	57·0							45·2	66·3

N.B. WHERE THE 200 MESH SCREEN WAS NOT USED, THE −120+200 MESH PRODUCT SHOULD READ −120 MESH. ALL VALUES OF WT AND Fe ARE IN PERCENTAGES

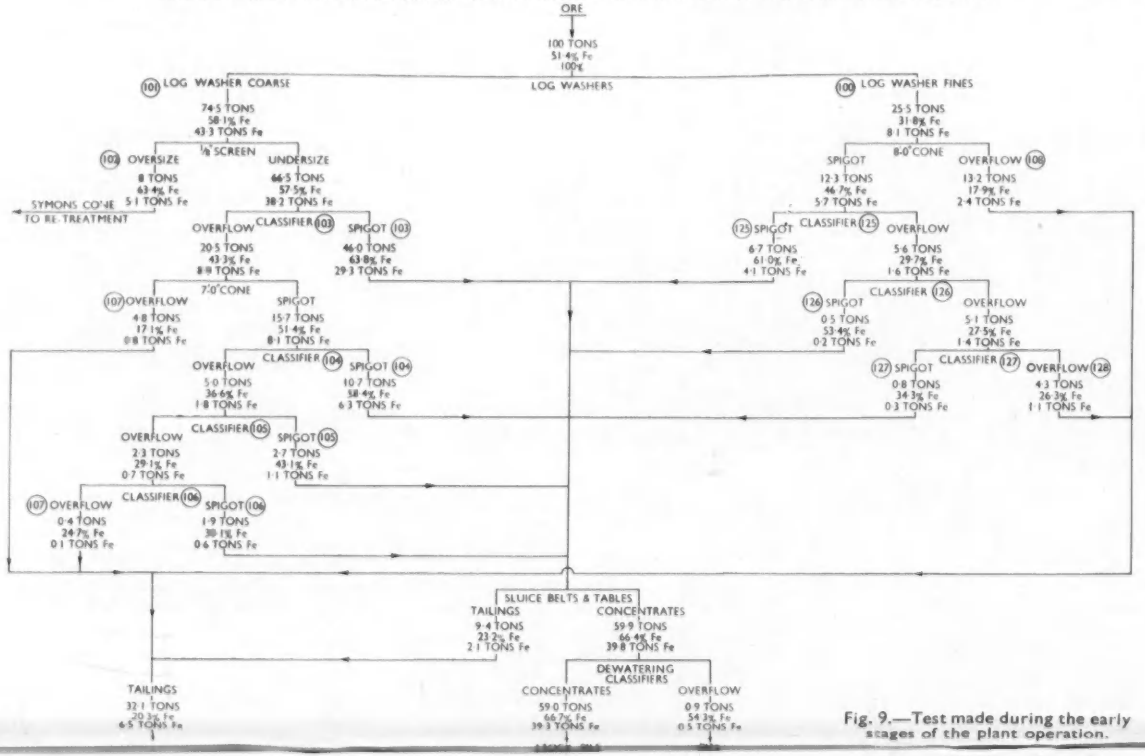


Fig. 9.—Test made during the early stages of the plant operation.

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D.S.F. type Dorr classifiers no. 42 set at 3 ins. per foot slope. Each machine does 15 strokes per minute, and is driven by a 5-h.p. motor.

The overflows from the classifiers enter settling pits in order to take out the very fine particles of ore which occurred and which were found to cause wear on the 6-in. Gwynnes pump,

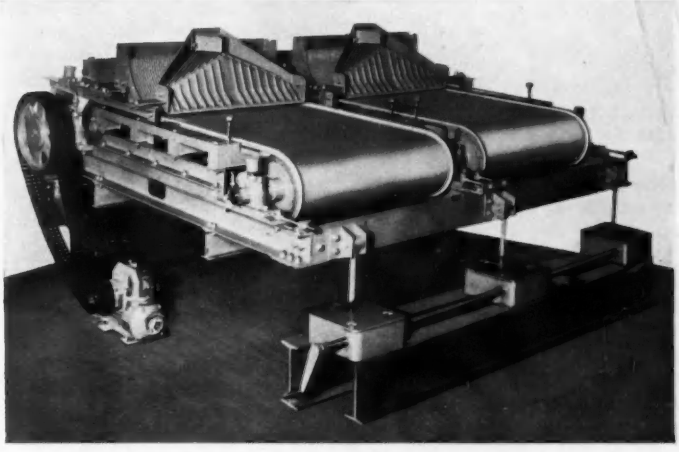

Fig. 10.—Double sluice machine.

which returns the recovered water to the log washers.

The concentrates are discharged from the classifiers on to conveyor no. 6, which transports them to the concentrate stock pile. This conveyor is fitted with a Blake-Denison automatic weigher.

Fig. 9 gives the percentage weights and screen analyses of various products taken during the early stages of the plant operation from section 3 of the mill.

The grade of the concentrate made is 67 per cent Fe. The extraction of the iron from the feed, to the sluice belts and tables is high. The quantity of iron recovered on the sluice belts has been more than 70 per cent of the total iron in the feed, but this quantity can be varied to meet the characteristics of the ore under treatment. There is approximately 9 per cent of the Fe in the overflow fines from the cones and classifiers no. 106 and no. 127, which are relatively high in phosphorus.

A service trolley at the side of the building, serves the six floors of the plant. It is operated by a single drum motor-driven haulage ; the gross load is 6,480 lbs., the speed of travel 50 ft. per minute, the driving motor being a 7½-h.p. machine.

ELECTRICAL EQUIPMENT.

The installation of the electrical equipment was planned in collaboration with Mr. D. Selby Bigge and Company, the consulting engineers for the Sierra Leone Development Company.

The electric supply at 3,300 volts is brought, through a 900 kVA three-phase, 3,300/500-volt transformer, to a 500 volt main switchboard. From this point the whole of the electrical equipment, which is on a considerable scale, was designed, manufactured and supplied by the G.E.C.

From a substation equipped with a 10-panel, 500-volt, 25 MVA, S.V.D. type switchboard, main distribution circuits are taken to seventeen contactor type switchboards located in suitable positions through the plant. Sixteen heavy duty ironclad distribution boards of the industrial type deal with the various subcircuits.

There are, in all, 113 motors, of both squirrel cage and slipring types, ranging in size from ½h.p. to 135 h.p., and totalling 1,176 h.p. All motors are three-phase, totally enclosed, dust- and weather-proof machines, and are fan-cooled where necessary. The squirrel cage machines are provided with totally enclosed, dust- and weather-proof direct-to-line starters, while the slipring type motors are equipped with rotor starters electrically interlocked with the stator switches where required.

The vibratory movement of the 106 concentrating tables is provided by a direct current electromagnetic system and two motor generator sets are employed to supply the necessary power.

Each set consists of a 135-h.p., 500-volt, 970-r.p.m. three-phase protected type slipring induction motor coupled to a 100-kW, 220-volt D.C. generator. A seven-panel open-type flat back switchboard controls the two generators and four outgoing feeders.

Certain of the conveyors and haulages are equipped with electromagnetic brakes.

The complete lighting installation throughout the Works, including the various types of fittings and lamps, was designed and installed by the G.E.C. Power for lighting is obtained from a three-phase oil-immersed, self-cooled indoor transformer, having an output of 75 kVA and a voltage ratio 3,150/400.

In addition to the H.T. and L.T. mains, over 10 miles of wire were used on the various power and lighting circuits.

The whole equipment with the exception of the thickeners is housed in a substantial structural steel building. The building and bunker are covered by 20 W.G. galvanised corrugated sheeting, while the ridging on the span roof, the sides and the ends of the building are covered by 22 W.G. galvanised corrugated sheeting.

The weight of the materials for the buildings and bin was 1,100 tons and 1,700 tons for the machinery and electric motors, making a total of 2,800 tons.

MILL CONTROL.

For the metallurgical control of the mill the weights of the feed and the concentrates are taken by automatic weighing machines. Hand samples of the feed and the concentrates are taken at regular intervals. Elmore Samplers take the tailings sample and the overflows from the cones and classifiers no. 106 and no. 127. Regular samples are taken for the determination of the pulp densities at important points in the flow sheet in order to maintain the correct conditions.

WATER SUPPLY.

The pump station is a little less than one mile from the plant and is situated on a tributary of the Rokel River. Here there are two 12-inch Medivane pumps, each driven by a 600-h.p. motor. The total head is 330 feet and the capacity of each pump is approximately 4,500 gallons per minute. One set is used as a standby. These pumps serve other sections of the property in addition to the mill. The make-up water used in the concentrator may be from 350 to 750 gallons per minute depending on the densities of the spigot discharge from the thickeners.

PERSONNEL.

The mill works three shifts of eight hours each. There are eight European and 200 African employees, including the mill superintendent and the men engaged on maintenance work.

HANDLING CONCENTRATES.

There are two electric shovels, 1½ cubic yards capacity, for loading the concentrates from the stock pile into 30-ton all-steel wagons.

For the transport service there are Garratt-type locomotives each taking an average gross load of 1,500 tons.

At Pepel a tippler unloads the ore from the wagons into a hopper fitted with three Sherwen feeders which feed the conveyor system transporting the ore to a travelling bridge for stocking out. The iron ore is scraped from the pile to a receiving hopper by two Sauerman 4½ cubic yard scrapers. A 42-inch belt conveyor transports the ore directly to the ship and has a loading rate of 1,500 tons per hour.

ACKNOWLEDGMENT

The author wishes to thank The Sierra Leone Development Company for their permission to publish the foregoing information and photographs.

Novel Developments in Design and Operation of A.C. Welding Plant

By E. C. DAVIES, A.M.I.E.E.
Witton Engineering Works.

This paper was first presented to the Birmingham Branch of the Institute of Welding on March 14th, 1947, and subsequently at Olympia during a Welding Symposium organised by the Institute of Welding on the occasion of the Engineering and Marine Exhibition in September, 1947.

Beginning with a critical examination of the inherent shortcomings of the present types of A.C. welding plant, the author points out the directions in which development work is proceeding and gives the results of some recent investigations.

FOREWORD.

IT is generally recognised that the future prosperity of this country depends very largely on the ability of British industry to compete successfully in the world markets. The situation therefore demands a progressive outlook with the ability and desire to be " one jump ahead " of progress achieved in other countries.

This is particularly true in the case of fabrication by arc-welding, which now plays such an important rôle in industry, and it becomes of increasing importance to take full advantage of the latest practice in design, shop methods and plant.

Welding plant manufacturers, whose experimental work was somewhat restricted during the war, have now an opportunity to contribute towards this objective, and their efforts may be expected to result in plant and apparatus having improved performance and other advantages. The welding engineer should be aware of developments in this field and the following notes are intended as a guide to indicate the trend of future progress in connection with plant involved in alternating current arc-welding.

They include a brief review of some recently completed developments, together with references to a few promising investigations at present in the experimental stage.

ADVANTAGES AND DISADVANTAGES OF EXISTING PLANT.

Dealing first with transformer type plant for manual welding, it can be stated that the present stage of popularity among users in this country, and to a rapidly increasing extent in U.S.A. and elsewhere, is due to :— (1) the availability of suitable electrodes ; (2) low first cost ; (3) low installation cost, as this plant is weather proof and may be used in the open without further protection ; (4) low running cost, owing to high electrical efficiency and negligible maintenance charges ; and (5) absence of arc-blow.

There are, of course, compared with D.C. plant, a number of disadvantages, which it should be remembered, owing to ignorance or prejudice, are often overemphasised. They do, however, indicate the direction in which future improvements are likely to be introduced, and may be summarised as : (1) low inherent power factor ; (2) unbalancing effect on three-phase supply system ; (3) increased danger from shock ; and (4) unsuitability for certain non-ferrous work.

Examining these disadvantages in more detail, it is seen, for instance, that the average power factor of a single operator welding transformer, owing to the inductance incorporated in the secondary circuit, is usually between 0·35 and 0·4. Whether this is a detriment to the user, however, depends upon whether or not he is penalised by the local supply authority for low power factor, and also whether the welding load is an appreciable proportion of the total shop load.

In cases where the power factor must be improved, the present solution lies in connecting a suitable static condenser across the primary terminals.

This naturally increases the cost of the installation, but it must be recognised that even so the total expenditure is appreciably less than for an equivalent D.C. set. The capacity of condenser selected for this purpose is usually between one-third and one-half of the continuous welding rating of the transformer.

It cannot be denied that there is some justification for the criticism that the welding transformer

causes some unbalance on the normal three-phase power supply. The welding arc draws its energy as a single-phase load and, if connected to a three-phase system, is bound to load the three lines unequally. The use of so-called three-to-one phase transformers, two examples of which are

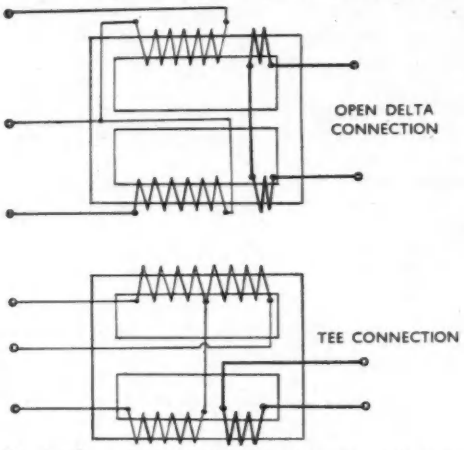

Fig. 1.—Two examples of three-phase to single-phase welding transformers in common use.

shown in fig. 1, is sometimes advocated, but, as shown in fig. 2, a measure of balance is obtained only at the expense of 16 per cent additional current in one line, and at an increased cost of plant.

There is no doubt that the straight single-phase set, connected across two lines of the three-phase supply is preferable, and in most cases, where the welding load represents perhaps 25 per cent or less of the total, the unbalancing effect is small enough to be ignored. It is obvious, of course, that, so far as practicable, steps should be taken to ensure that, where a number of sets are involved, an approximately equal number should be connected to each phase. Experience has shown that difficulties arise mainly on small installations where the welding load may be an appreciable percentage of the total demand and where less than three sets are installed.

The effect of shock from an alternating current welding circuit is usually more severe than from direct current, partly because the peak voltage is about 40 per cent higher and also because it is sometimes difficult to release the grasp under conditions of alternating current shock. As the striking voltage of welding transformers does not normally exceed 100 volts, however, danger to life is usually confined to operatives in restricted spaces and in elevated positions when a sudden shock may lead to loss of foothold.

With modern electrodes the welding transformer may be used with confidence for work on steel and most of the ferrous alloys. So far, however, electrodes for aluminium and its alloys and some of the bronze rods are not suitable for use with normal 50-cycle welding plant.

It may be that some time in the future electrode manufacturers will succeed in producing electrodes for this purpose, but, in the meantime, it is recognised that in order to provide satisfactory welding conditions for these non-ferrous electrodes the characteristics of A.C. plant must be adjusted to suit the special requirements of this type of arc.

RECENT IMPROVEMENTS.

Some of the problems outlined above have recently been solved and the elimination of the shock hazard is one of them.

One method which has found favour abroad and which has also been used in this country involves a means by which the voltage of the transformer is reduced to a low value whenever welding is discontinued. This may be achieved in a number of ways, one of which is shown in fig. 3. In this case the open circuit voltage of the transformer is reduced to twenty volts or so by means of a reactance R_1 connected in series with the primary winding. The values of the

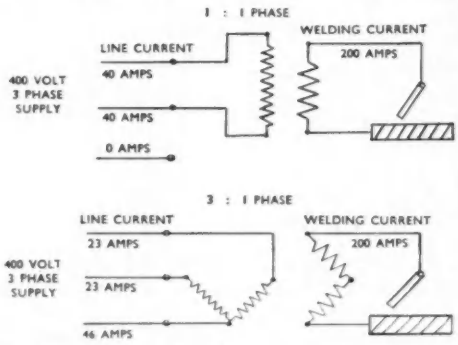

Fig. 2.—Primary currents for a given welding load on single-phase and three-phase to single-phase welding transformers.

balancing reactances R_2 and R_3 are so chosen that when no welding is in progress the voltage between terminals A and B is substantially zero. On touching electrode to workpiece, the current in the primary winding of the transformer is increased and a voltage appears across A-B, causing current to flow through the contactor coil X_1. The subsequent operation of the contactor short-circuits the reactance R_1 and applies full voltage to the transformer.

At the same time operating coil X_1 is de-energised by the opening of contact C_2. The contactor is now held in by coil X_2, which is in series with the transformer primary winding, and in consequence an interruption in the welding circuit causes the contactor to drop out and reinsert the voltage limiting reactance R_1. There is much to be said for this solution, but the obvious objection is the cost of the extra equipment, one set of which would be required for every welder.

The other method which has been recently developed avoids the complication of additional control gear by incorporating in the electrode holder a switch which enables the operator to isolate all exposed metal portions from the welding supply at will. Fig. 4 shows a cross section of this type of holder and it will be seen that the switch is operated by depressing the external lever. This is lightly spring-loaded to allow the switch to open when pressure is released, but very little effort is required to hold it in the closed position.

Electrodes are gripped by the spring-loaded central plunger which is retracted for electrode replacement by an *outward* movement of the lever. This ensures the complete isolation of the supply when changing electrodes—perhaps the most useful feature of the holder. Also, unlike the so-called " all insulated " holder, when not in use the electrode as well as the holder is disconnected from the supply. Although in service the welding current is normally broken at the arc, the switch contacts are designed to break the full welding current in the event of the operator wishing to do so ; as for instance, in the event of a " frozen " electrode. Fig. 5 shows the method of inserting an electrode, and fig. 6 the holder in use.

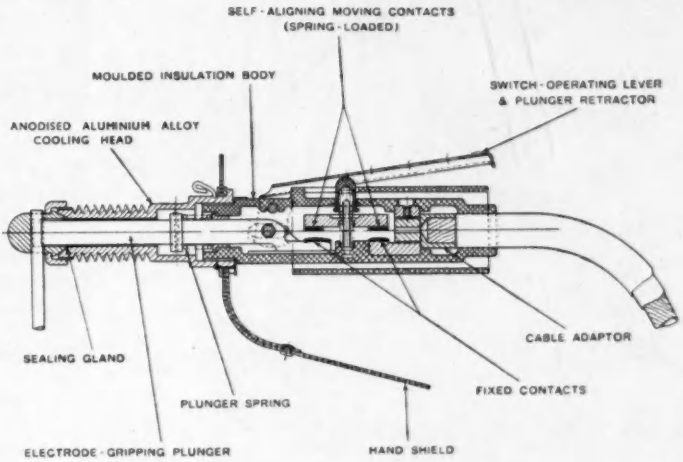

Fig. 4.—Sectional drawing of safety type electrode holder.

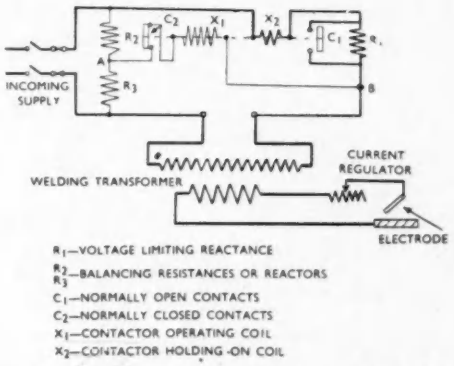

Fig. 3.—One example of a voltage-limiting circuit for use in conjunction with single-operator welding transformers.

WELDING OF NON-FERROUS METAL.

The problem of making A.C. welding applicable to non-ferrous work, such as aluminium, etc., has received considerable attention by plant manufacturers and certain improvements have already been made. In order to appreciate the problem, it should be remembered that on a 50-cycle supply the A.C. arc is extinguished 100 times per second and for stable welding conditions re-ignition should take place regularly and with minimum delay, as indicated in figs. 7 and 8 The factors controlling this re-ignition are partly electrical and partly thermal.

At each instant of zero current the welding plant must provide the minimum voltage necessary to re-strike the arc, but the actual value is determined by the composition of the materials involved—electrode, flux coating and workpiece —and their momentary temperature. For instance, at room temperature several thousand volts are required to break down the normal gap of $\frac{1}{8}$ in., but the emission of electrons or " ionisation " which occurs at welding temperature has the effect of lowering the effective resistance to

the passage of current across the gap and the re-striking voltage during welding is, therefore, reduced normally to less than 50 volts.

A.C. welding on ferrous materials is satisfactory because, first, the fluxing materials commonly used emit electrons freely at welding temperatures and, secondly, when molten they blanket the metal pool and help to maintain its temperature during the critical periods when the arc energy is low.

Fig. 5.—Method of inserting electrode into safety type electrode holder.

The difficulties when dealing with aluminium and the copper alloys are first that the flux coatings of electrodes at present available have not such good ionising properties as those used for ferrous work, and the blanketing effect is not sufficient to prevent excessive variations in temperature which occur under 50-cycle welding conditions due to the high thermal conductivity of these metals.

It can now be appreciated that improved performance should result from (1) increasing the ionisation in the arc gap by the use of modified fluxing materials or by some other method, or (2) reducing the cyclic variation in temperature of the molten pool by increasing the frequency of the welding supply.

Whether the electrode manufacturers will succeed in producing aluminium electrodes suitable for normal 50-cycle welding remains to be seen, but some progress has been made by plant manufacturers towards a solution based on the provision of increased arc-gap ionisation by means of electrical devices. One method which is fairly well known employs the so-called pilot arc principle, in which a separate low-energy high-frequency source of supply is connected between electrode and work.

The voltage generated by this auxiliary equipment is high enough to break down the resistance of the arc gap and to cause an electrical discharge to be maintained across it. This intense ionisation may thus be regarded as "blazing a trail" for the main welding arc, the cyclic re-ignition of which is thus facilitated despite the periodic temperature variations mentioned above. In practice the high-frequency attachment may be of the valve oscillator or spark-gap type. Fig. 9 (*a*) shows the circuit used in one form of the latter in which the spark gap is used as an interrupter in a resonant circuit consisting of a condenser C and an inductance L_1, the latter forming the primary winding of a step-up auto transformer.

The frequency of the oscillations produced in the resonant circuit may be of the order of 200,000 to 500,000 cycles per second and the pressure induced across the transformer primary winding L_1 is stepped up to the several thousand volts necessary to provide the required ionisation between electrode tip and workpiece. A safety

Fig. 6.—G.E.C. safety type welding electrode holder in use.

park gap G is provided to limit the voltage generated before the main circuit across the arc gap is completed, and the by-pass condenser

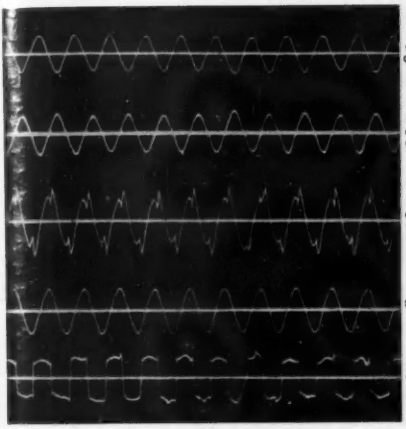

Fig. 7.—Characteristics of welding transformer indicating sinusoidal current wave form and corresponding arc stability.

C_2 prevents the high-frequency currents from flowing in the windings of the main welding transformer.

An interesting alternative method of obtaining the high-frequency auxiliary supply is at present being investigated and is shown in fig. 9 (*b*). In this case the high-frequency oscillations are excited by a current transformer T_1, in series with the main welding circuit and tuned to the desired frequency by selecting suitable values for the inductance L and the condenser C. This arrangement has the advantage of dispensing with the complication of a separate supply to the oscillator and is less disturbing to the operator, since the high-frequency energy is applied only while the welding arc is maintained. Fig. 10 illustrates a typical spark-gap oscillator.

As already mentioned, the stability of an A.C. arc on non-ferrous work may be improved by increasing the frequency of the welding supply, since at high periodicities the cyclic variations of temperature of the materials providing the ionising conditions are correspondingly reduced. In practice it has been found that a noticeable improvement takes place at frequencies of the order of 150 cycles

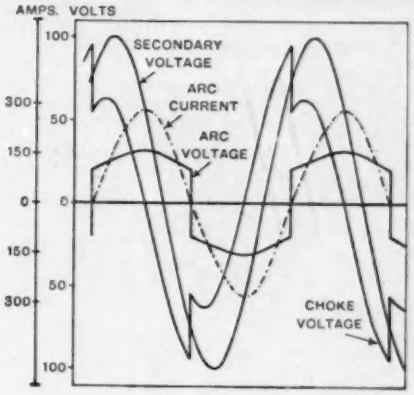

Fig. 8.—Theoretical wave forms of voltage and current in a welding transformer with choke stabilisation of arc.

per second and that at 500 cycles per second conditions are equivalent to the direct current arc.

Unfortunately, it is not likely that static welding plant at this frequency will become economically possible and therefore present develop-

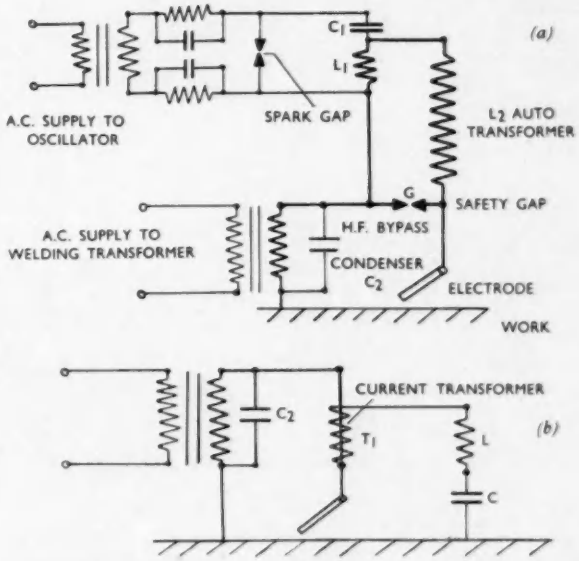

Fig. 9.—Examples of superimposed high-frequency ionisers :
(*a*) Spark gap, separately energised type ;
(*b*) Self-excited generator.

ments are mainly concerned with rotating plant of various types. The designer's problem largely boils down to the provision of an alternating current generator which would be competitive in performance and cost with a direct current machine of similar output.

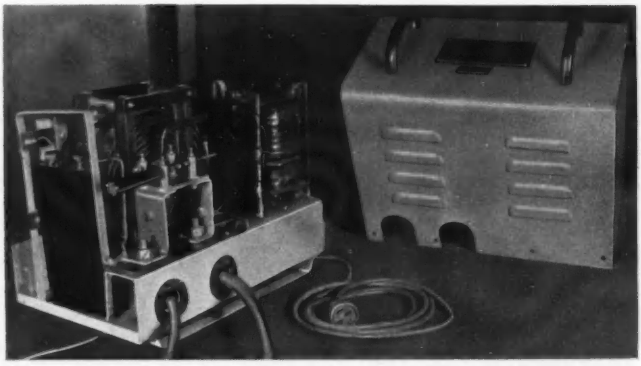

Fig. 10.—Interior of one type of spark-gap ioniser (*The Arc Manufacturing Company*).

The chief advantages of such a plant would be the absence of arc blow which is often troublesome with the direct current arc, and reduced maintenance charges resulting from the elimination of commutator and brushgear. Several manufacturers have already produced 500-cycle welding sets, and some hold the view that if produced in sufficient quantity they could be made at a lower cost than equivalent direct current sets.

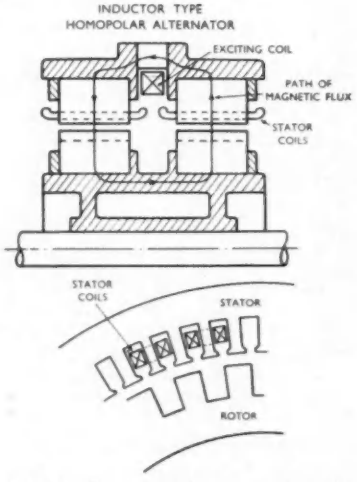

Fig. 11.—Fundamental construction of inductor type homopolar alternator.

Fig. 11 shows diagrammatically the construction of one type of high-frequency alternator, one of the principal advantages of which is the simple form of the rotor which merely consists of a hub carrying two toothed wheels which are usually built up from sheet steel stampings and carry no windings.

This type of alternator is usually driven by a direct coupled A.C. motor, but in a modified form the rotor is provided with a squirrel cage winding and an additional three-phase winding is located in the bottom of the stator slots. This machine runs as a motor from the 50-cycle supply and at the same time generates the high-frequency welding supply as an inductor alternator, thus dispensing with the need for a separate motor.

Before leaving the subject of the welding of "difficult" materials by the A.C. arc, a passing reference should be made to the twin carbon technique which can be used with standard transformer plant. The arc is struck and maintained between two carbon electrodes, which are manipulated as in gas welding, the added metal being supplied from a filler wire. Fig. 12 shows one form of electrode holder developed for this purpose.

The method may be used for brazing or welding and has been found particularly useful for repair work on thin sheet metal such as car wings, etc. Fig. 13 illustrates the technique employed.

SUPPLY CONSIDERATIONS.

As already stated, the effect of transformer

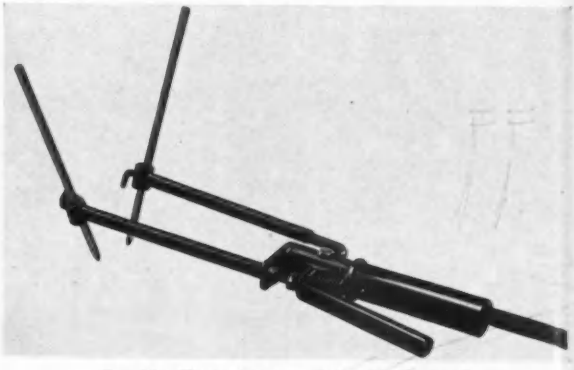

Fig. 12.—Typical twin carbon welding torch.

Fig. 13.—Twin carbon welding torch in use.

welding plant on the loading of the supply mains is usually only troublesome when fewer than three sets are installed in a shop where the remaining load is small.

Of the suggestions which have been made to solve the difficulty, one of the most interesting is the use of the multi-phase arc. As early as 1920 a proposal was made with the object of utilising three phases at the arc and thus to draw balanced currents from the three-phase supply. Fig. 14 shows the method suggested which involves the use of two electrodes simultaneously, fed from two phases of the three-phase welding transformer, the third phase of which is connected to the workpiece.

The electrodes are insulated from each other so that successive arcs develop between no. 1 electrode and workpiece, no. 2 electrode and workpiece and between electrodes, and for conditions of balanced power input these three arc currents must be equal in magnitude.

In practice it was found that the resulting welding conditions were not satisfactory for normal work, as the melting rate of the electrode was excessive for the heat input to the workpiece and the deposit lacked penetration. The difficulty could be overcome only at the expense of upsetting the conditions necessary for balanced power input. Quite recently a considerable amount of experimental work was carried out on somewhat similar lines and the results have been distinctly encouraging.

Fig. 15 shows the modified arrangement in which the twin electrodes are now supplied from a three- to two-phase transformer and the work is connected to the neutral terminal of the two-phase secondary winding. Without elaborating the theoretical aspects, it may be stated that the main reason for the successful operation of this system is that during welding the effective resistance between each electrode tip and workpiece is considerably less than that between the two electrode tips and, in consequence, practically all the current passes between workpiece and each electrode in turn, and a balanced load is taken from the three-phase supply to the transformer. Arc stability and the thermal efficiency are greatly improved, since the two arcs burn alternately and one is always maintained during the reversal period of the other.

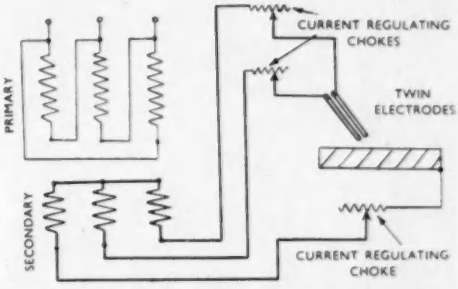

Fig. 14.—3/3 phase twin metallic arc-welding circuit.

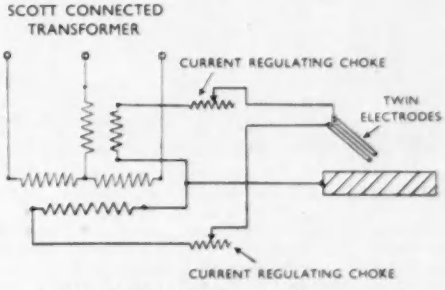

Fig. 15.—3/2 phase twin metallic arc circuit.

1 phase 408 volts—striking voltage 100					
Operation—$\frac{1}{4}$ in. Fillet.					
Electrode—Type A. 4 S.W.G.					
Primary Current	kVA	kW	Welding Current (per Rod)	Welding Speed (Arc Time)	Power Factor
93.5 amp.	38.1	13.1	324	1.4 ft. per min.	0.34

Twin Arc 3/2 phase, 407 volts—striking voltage 63					
Operation—$\frac{1}{4}$ in. Fillet.					
Electrode—Type A. 6 S.W.G.					
Primary Current	kVA	kW	Welding Current (per Rod)	Welding Speed (Arc Time)	Power Factor
51.3 amp.	36.24	15.4	249	1.77ft.per min.	0.43

Fig. 16.—Relative welding performance, one-phase and twin arc.

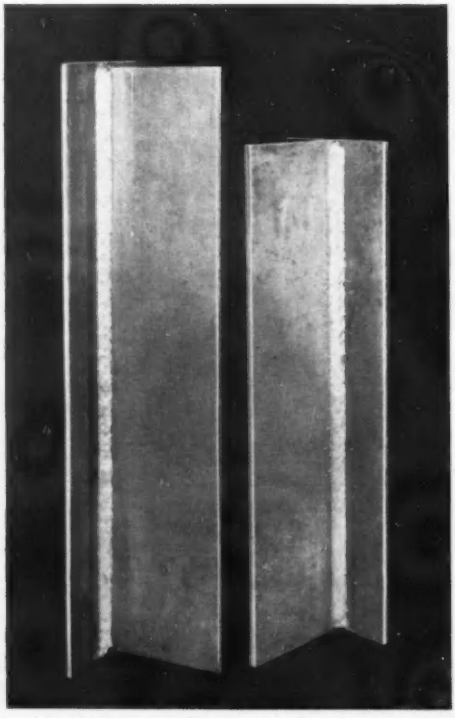

Fig. 17.—Comparison between single-arc and twin-arc fillets referred to in the table (fig. 16). On the right is seen the deposit obtained from a 4 S.W.G. single electrode supplied from a single-phase source; on the left is the deposit obtained from one double 6 S.W.G. electrode supplied from a three-phase to two-phase source. Note the considerably greater length of deposit and improved appearance obtained with the twin-arc system as compared with normal single-phase welding.

Comprehensive tests show a number of important advantages as compared with normal single-phase welding. For instance, with equal kVA input the rate of deposition from the two-phase arc is about 30 per cent faster than is possible on single phase. As the load on the three-phase supply is balanced the line current under these conditions is less than 60 per cent of that taken by the single-phase welder as indicated in fig. 16.

In a typical $\frac{1}{4}$ in. fillet weld the arc is noticeably quieter than normal and the appearance of the weld is remarkable for its smoothness and lack of spatter as can be seen in fig. 17. The normal penetration which is obtained is shown in fig. 18. A striking voltage of 60 volts is satisfactory for most electrodes used in this manner, an obvious advantage in reducing the risk of shock, and the power factor without correction is at least 25 per cent better than on normal single-phase sets.

In practice it is convenient to use two electrodes side by side, either clipped together or cemented in the process of manufacture. The flux coating acts as an insulator between the metal cores, and a modified form of electrode holder (fig. 19) is necessary to connect the two-phase supply to the bared ends. A twin-arc welding transformer is shown in fig. 20.

It may be of interest to record that a somewhat similar system has been developed on the Continent for automatic welding.

AUTOMATIC WELDING.

In the field of automatic A.C. welding a number of innovations have been introduced recently with the object of simplifying the plant and reducing welding costs. One of these concerns

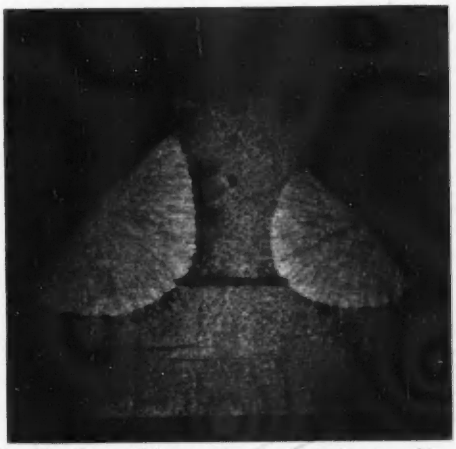

Fig. 18.—Typical fillets produced with twin-arc-welding, showing the normal depth of penetration.

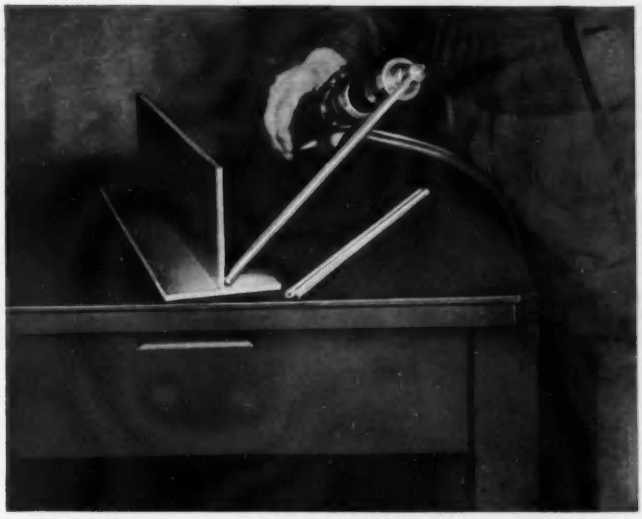

Fig. 19.—One form of double electrode holder for twin-arc-welding. A cemented twin electrode is shown alongside the work.

equipment used for controlling arc length during a welding operation. In most systems at present in use the arc length is maintained at a predetermined value by controlling the speed of the motor driving the electrode feeding mechanism.

This motor is normally a direct current machine fed from a small motor generator set, and its speed is controlled by varying the voltage of the generator by electronic or other means operating in its field circuit. The basis of control is the arc voltage which is approximately proportional to arc length, and discrepancy between the actual value and a selected reference voltage is, therefore, used to adjust the rate of electrode feed in such a way as to restore the arc length to the

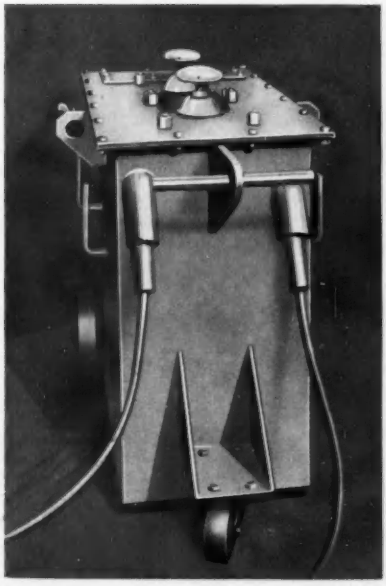

Fig. 20.—Twin-arc welding transformer showing duplicated controls which enable the set to give two independent single-phase welding supplies.

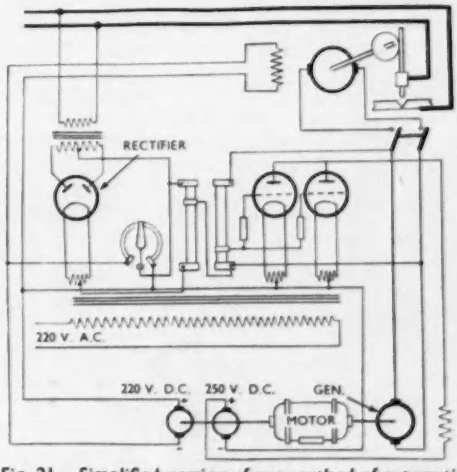

Fig. 21.—Simplified version of one method of automatic arc control as used for submerged arc-welding.

desired value. One example of this type of control is given in fig. 21.

Recently a new form of arc control has been developed which eliminates much of the external apparatus previously used, and has proved to be particularly applicable to the submerged arc process. In this case the speed of the feed motor is selected for a given welding operation and remains constant during the run. The current required is set in the usual manner by adjusting the regulator of the welding transformer. From the moment the arc is struck its length is then controlled entirely by the electrical characteristics of the welding transformer.

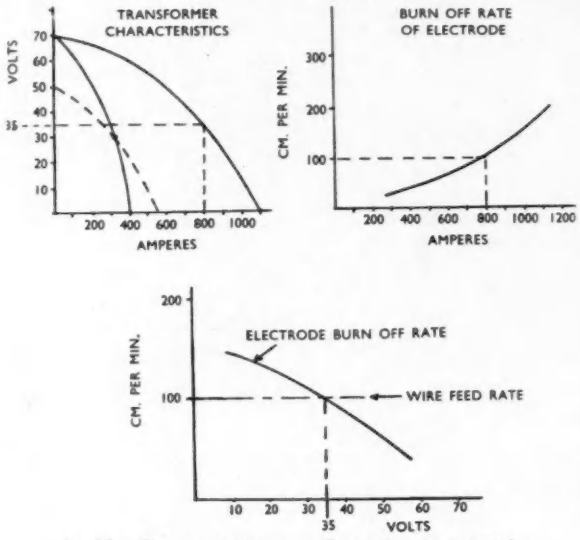

Fig. 22.—Characteristic curves illustrating the principles involved for obtaining self-stabilising features from transformers designed for automatic arc-welding.

The principle involved is simple and briefly is as follows :—For a given rate of feed, a constant arc length will be obtained when the electrode tip melts at the same rate as the wire is fed forward. The initial settings of feed speed and welding current are, therefore, selected to ensure this condition, since the current controls the melting rate of the electrode. The welding plant, however, is so designed that any variation in arc length and, therefore, in arc voltage results in a predetermined change in welding current.

A disturbance during welding, which causes a momentary reduction in arc length, thus produces an immediate increase in current and a corresponding increase in melting rate, by an amount which restores the arc length to its original value in the time required for effective control. The reverse occurs when the arc length is momentarily lengthened. For any given electrode size it is a comparatively simple matter to calculate the volt-ampere characteristic required from the welding transformer to achieve this automatic control of arc length. In order to cater for a range of electrode diameters the welding plant characteristic has to be made adjustable over the working range, and in practice this is done by varying the open circuit voltage, as shown in fig. 22.

By eliminating such delicate components as valves, relays, etc., the new control system is likely to become popular if only on the score of freedom from maintenance troubles.

Although not strictly within the scope of this paper the following process is included as an example of a novel application of A.C. automatic arc-welding.

The procedure is a development of the Elin Hafergut or Firecracker system, but in this case the electrode is uncoated and the arc is submerged beneath a layer of powdered fluxing material. Fig. 23 shows the principle. The electrode is located at the correct distance from the workpiece by an adjustable clamp at one end, and a small carbon bush at the other. An experimental rig is illustrated in fig. 24.

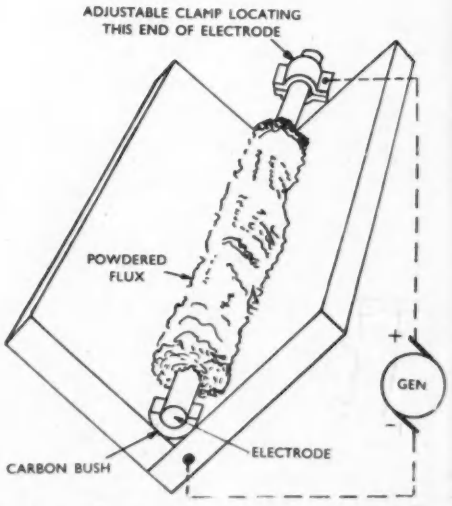

Fig. 23.—Diagrammatic representation of one form of automatic arc-welding employing a bare horizontal electrode surrounded by a powdered fluxing material.

Granulated flux is poured over the whole length of the rod and the welding supply is connected between the clamp and workpiece. The arc is struck automatically beneath the layer of flux at the carbon bush and thence continues to burn and fuse the rod at a uniform speed. At the end of the run, surplus flux is removed and may be used again. The process has obvious limitations, but for certain types of repetition work has distinct possibilities, as unskilled labour can be employed and extremely heavy deposits can be laid down in a single pass.

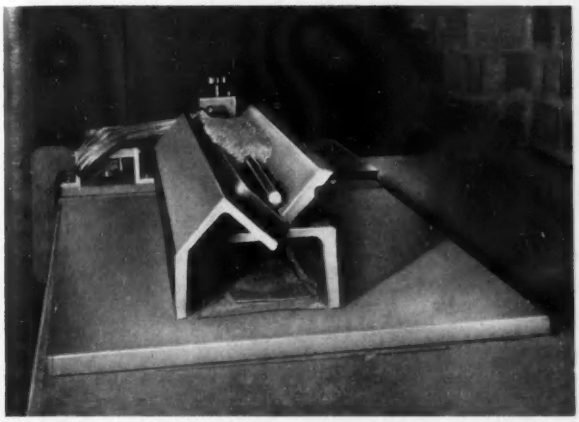

Fig. 24.—Laboratory set-up for the method of welding shown in fig. 23.

Recent experiments indicate that certain precautions should be observed in order to obtain consistent results. The arc gap in relation to the current strength and electrode diameter is fairly critical, but can be determined from trial runs. It is also necessary to ensure that the electrode is stress-free, otherwise it tends to distort when hot and vary the arc gap. For obvious reasons, welding must take place in the natural gravity position.

In practice it is desirable to avoid tacking and to employ a jig to hold components in position during welding. Preferably, the jig should be made rotatable to facilitate the positioning of components and the removal of surplus flux powder.

Deposits made by this process have a smooth appearance as depicted in fig. 25, and, as cooling is delayed by the heavy flux covering, the mechanical properties are excellent.

WELDING MONITOR.

The apparatus sometimes referred to as the Welding Monitor has been in use in other countries for some years, but as one type suitable for A.C. welding was developed recently at the request of a member of this Branch, it might be of interest to conclude with a brief description of its functions.

Essentially it is a means of checking the arc length maintained during manual welding and as such is particularly useful for training purposes, although it may be of assistance to the experienced operator when engaged on work of special importance.

Fig. 26 illustrates the control cabinet which is provided with a voltmeter for measuring the voltage between electrode and work, red and green indicating lamps and two rheostats calibrated in volts.

In operation one rheostat is set to the voltage corresponding to the minimum arc length required, the other being adjusted to the upper limit of arc voltage. Relays operating contacts in the indicating lamp circuits ensure that whenever the selected limits of arc length, and therefore arc voltage, are exceeded, one or other of the lamps is illuminated. Excessive arc length lights the red lamp and too short an arc the green.

A feature of this apparatus is that as each limit is approached the corresponding lamp commences to flash, thereby calling attention to the condition. An excessive error causes the lamp to burn steadily. It is usual to provide duplicate lamps in the welder's hand- or head-shield to enable both him and the supervisor to notice the warning signals.

Before striking the arc the red lamp burns to

Fig. 25.—Example of heavy fillet produced by the method of welding shown in fig. 24.

indicate that the electrode holder is alive, but during a welding operation, if the limits have been set correctly, both lamps are extinguished while the arc length is maintained between the selected limits. It will be appreciated that the monitor thus indicates not only the ability of an operator to maintain a reasonably constant arc length, but also whether he tends to hold too long or too short an arc.

In practice it has been established that an experienced welder can maintain an arc length between the corresponding voltage limits of minus one volt and plus two volts. A normal trainee at the commencement of his course works between the limits of minus two volts and plus four volts. Experience has shown that, correctly used, the apparatus can be of considerable assistance in reducing the time required for training purposes.

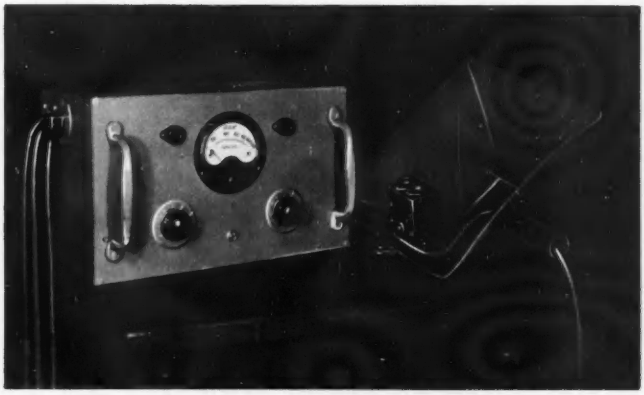

Fig. 26.—A welding monitor designed for use on a normal A.C. power supply, showing red and green indicator lamps on the monitor which are duplicated on the hand-shield seen on the right.

Technical Literature

A DIGEST OF RECENT BOOKS, ARTICLES AND PAPERS BY MEMBERS OF THE G.E.C. AND ITS ASSOCIATED COMPANIES.

THE INFLUENCE OF MECHANISATION ON COAL PREPARATION.

By H. G. Hague (Fraser & Chalmers Engineering Works, Ltd.)
A paper read before the Institute of Fuel, South Wales Section, February 14th, 1948.

The increased mechanisation of coal-getting is altering the characteristics of the raw coal to an extent that existing coal cleaning plants can no longer deal with the material satisfactorily. Reduced production costs are frequently accompanied by losses due to greater discard and smaller, less valuable size. Also, dust suppression results in wet coal. Coal preparation engineers are having to design plant to deal with these conditions.

EFFECT OF CENTRIFUGAL FORCE IN AXIAL FLOW TURBINES.

By B. Pochobradsky (Fraser & Chalmers Engineering Works, Ltd.).
Engineering, Vol. 163, March 21st, 1947, pp. 205-207.

The author considers the effect of centrifugal force in a turbine stage limited by two concentric cylindrical surfaces and indicates a blading design in which the centrifugal force is balanced by reaction increasing from root to tip and the radial distribution of the working medium remaining unchanged during its passage through the stage. In such blading there is no radial velocity component, which would be useless and harmful. Subsonic as well as supersonic cases are examined.

OPERATION AND MAINTENANCE OF COLD CATHODE FLUORESCENT LIGHTING FITTINGS.

By C. Dykes Brown (Illuminating Engineering Department). *Light and Lighting, July 1947, and "Osram Bulletin," Vol. 24, No. 2, April, 1947.*

The article describes the electrical and photometric characteristics of cold cathode fluorescent lamps with particular reference to their use in self-contained lighting fittings. An explanation is also given of a circuit in which transformers are connected in tandem.

FLUORESCENT LIGHTING.

By M. W. Peirce (Illuminating Engineering Department). *British Engineering Export Journal, July 1946.*

A discussion on the merits of fluorescent lighting for industrial purposes, including references to some arguments which have been used against this form of lighting.

NEW LIGHTING FOR OLD BUILDINGS.

By E. H. Penwarden (Fittings Department), and S. Anderson (Illuminating Engineering Department). *Trans. I.E.S., December, 1946. A paper presented to a joint meeting of the Illuminating Engineering Society and the R.I.B.A. in London on November 6th, 1946.*

The need for modern artificial lighting in period buildings and in those of more recent origin is discussed. The bearing on the problem of modern lighting technique is examined and the characteristics of present-day lamps, with particular reference to their suitability, are outlined. Some notes are given for the guidance of fittings designers and architects on the disposal of auxiliary gear for fluorescent lamps, and on contemporary reflecting and diffusing materials. Several examples are illustrated and discussed.

ELECTRICAL TIMING CIRCUITS.

By H. J. N. Riddle (The Siemens and General Electric Railway Signal Co., Ltd.). *A paper read before The Institution of Railway Signal Engineers, February 3rd, 1947.*

The author confines himself to condenser-resistance circuits in combination with hot and cold cathode-discharge tubes and thermionic valves. Consideration is given to the characteristics of condenser charge-discharge circuits for neon tubes, the effects of supply voltage variations, utilising circuits for thermionic valves and low voltage valve timing circuits. Some special uses are also considered.

TURBO-ELECTRIC PROPULSION.

By C. Wallace Saunders and T. Halliday Turner (Marine Department). *A paper read before the Institute of Marine Engineers, November 11th 1947. Trans. Inst. Marine Engineers, January 1948.*

The paper forms part of a Symposium "The Engining of Cargo Vessels of High Power" and is based on information derived from existing ships with turbo-electric propulsion; it deals mainly with the steam end of the equipment. Particular attention is given to the utilisation of exhaust steam from boiler feed pumps during stand-by and slow-running, the efficient use of full steam during reversals, the advisability of having first critical speed well above the maximum running speed, turbine efficiency ratio and the methods of stating steam consumptions to ensure authentic data for main and auxiliary power. Trial readings and curves are given.

THE INSIDE OF ELECTRICAL MACHINES.

By R. H. Robinson (Witton Engineering Works, Birmingham).

A series of twenty-two articles on every form of insulation used in electrical machines, including a description of methods of construction, testing and inspection. The articles appeared in *The Electrician* over a period from April 26th, 1946, to March 28th, 1947. They have since been rewritten and fresh data added and will shortly be published in book form under the title *The Inside of Electrical Machines.*

THE RATING OF SMALL AND MEDIUM POWER THERMIONIC RECTIFIERS(327).*

By H. T. Ramsay (Research Laboratories). *Jour.I.E.E., Vol. 94, Part III, No. 30, July 1947.*

The rating of small and medium power thermionic rectifier valves in capacitance—input circuits is amended, so that the full-load conditions may be deduced from the basic properties of the valves. An investigation on the parameter values in equipments employing valves at less than their maximum output is included.

PRODUCTION OF WHITEHEART MALLEABLE IRON BY ANNEALING IN PARTIALLY BURNT TOWN GAS (330).*

By I. Jenkins and S. V. Williams (Research Laboratories). *Paper presented to the Forty-second Annual Meeting of the Institute of British Foundrymen, London, June 16th, 1945.*

The production of Whiteheart malleable iron by annealing in hematite ore is a gaseous process. Work on controlled atmospheres, for use in the electric furnaces, is described.

RADIO MEASUREMENTS IN THE DECIMETRE AND CENTIMETRE WAVEBANDS (332).*

By R. J. Clayton, J. E. Houldin, H. R. Lamont and W. E. Willshaw (Research Laboratories). *Jour.I.E.E., Vol. 93, Part III, No. 22, March, 1946, and Vol. 93, Part III, No. 26, November 1946.*

The technique of radio measurements evolved for the development of decimetre—and centi-

* A limited number of reprints is available; copies may be obtained on application to the Editor, G.E.C. Journal, Magnet House, Kingsway, W.C.2.

metre—wave valves, circuits and equipment is described. Circuit theory of coaxial and wave-guide transmission lines, high-frequency oscillators, measurement of fundamental quantities of frequency, power, impedance and voltage, heterodyne methods of frequency measurement, etc., are reviewed.

GAS-CARBURISING (340).
By I. Jenkins (Research Laboratories).
Metallurgia, Vol. 34, No. 202, August, 1946.

The mechanism of carburisation in solid and in gaseous media is discussed, and it is shown that in pack-carburising the atmosphere surrounding the work is rich in carbon monoxide and hydrogen. The hydrogen appears to play an active rôle, possibly by forming hydrocarbon gases which carburise the steel, or by promoting the removal of surface films of carbon dioxide. The condition of the steel surface before carburising may have a marked effect on the rate of carbon absorption. Activation of the surface by " gas-etching " leads to a very pronounced increase in the rate of carburisation above that obtained with rolled or machined surfaces.

ENERGY DISTRIBUTION IN THE SPECTRUM OF A FREQUENCY MODULATED WAVE—Part II (345).*
By A. S. Gladwin (Research Laboratories).
Phil. Mag., Ser. 7, Vol. XXXVIII, p. 229, April, 1947.

The energy spectrum of a frequency modulated wave may be calculated approximately when the energy spectrum and the statistical distribution of amplitude in time of the modulating wave are known. Examples of spectra for modulation by telephonic signals are given.

FURTHER STUDIES OF THE THERMAL PROPERTIES OF GLASS-MELTING TANK FURNACES (346).
By B. P. Dudding (Research Laboratories).
Transactions of the Society of Glass Technology 1946, Vol. 30, p. 243.

Data of the weekly glass production and weekly fuel consumption for a total of eight melting campaigns involving four different furnaces are studied in detail.

THEORY OF THE HIGH-PRESSURE MERCURY-VAPOUR DISCHARGE (349).*
By V. J. Francis (Research Laboratories).
Phil. Mag., Ser. 7, Vol. XXXVII, July, 1946.

An attempt to solve the energy balance equation for the positive column of the high-pressure mercury-vapour discharge is made. This enables relations between parameters to be studied for a wide range of pressures and operating characteristics.

PHOTOMETRY AND COLORIMETRY OF FLUORESCENT AND OTHER ELECTRIC DISCHARGE LAMPS (354).*
By G. T. Winch (Research Laboratories).
Trans. I.E.S., Vol. XI, No. 6, June 1946.

The progress from visual to photoelectric hetero-chromatic photometric techniques in accordance with C.I.E. recommendations is reviewed. A description is given of the design and performance of a new dispersion and mask type of photoelectric C.I.E. average eye, colorimeter and spectral band apparatus. Liquid filters for use with photocells approximating to C.I.E. average eye response and a new design of universal photoelectric photometer for use with them are also mentioned.

PHASE DETECTORS—SOME THEORETICAL AND PRACTICAL ASPECTS (355).
By L. I. Farren (Research Laboratories).
Wireless Engineer, Vol. XXIII, December, 1946.

The theory of operation of various forms of phase detector is developed, for the case when the applied voltages are sinusoidal and when they are rectangular. A number of practical forms of circuit are considered and the results of measurements made on these circuits are given.

THEORY OF THE HIGH-PRESSURE MERCURY-VAPOUR DISCHARGE (B) (356).*
By V. J. Francis (Research Laboratories).
Phil. Mag., Ser. 7, Vol. XXXVII, October, 1946.

The theory proposed in Communication 349 is further developed. An improved method of finding the values of the constants is used and curves are calculated relating the important discharge parameters over a wide range of operating conditions.

THE RELATION BETWEEN THE PHYSICAL PROPERTIES AND THE STRUCTURE OF GLASS. I. VARIATIONS OF THE PHYSICAL PROPERTIES WITH TIME. II. VISCOSITY AS A FUNCTION OF TEMPERATURE (369 and 370).
By R. W. Douglas (Research Laboratories).
Transactions of the Society of Glass Technology, 1947, Vol. 31, p. 50.

The X-ray diffraction patterns of liquids and glasses are compared: similarities between them enable a qualitative application of some theoretical work on the liquid state to be made to glasses. This account is given in terms of random network structure and involves no consideration of aggregation or association.

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